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I.—On Fitting Polynomials to Weighted Data by Least Squares.

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1. INTRODUCTORY.

THE present paper continues the study, initiated * in a previous paper, of methods of fitting polynomials to data by least squares, with the aim of systematising the numerical procedure. The case considered here is that of unequally weighted data. A further paper will deal with the still more general case of weighted and correlated data. The numerical methods put forward for the three cases are quite different, and the only common point in the theory is the use of orthogonal polynomials.

These problems, with the exception of the correlated case, were of course posed and solved more than seventy years ago by Tchebychef. Expositions and numerical illustrations of Tchebychef's method, which depended on continued fractions, have been given recently * by Chotimsky and Isserlis. We believe that the alternative derivations given below will be found simpler and more direct.

Theoretically, the problem of weighted data presents no special difficulty. Perhaps a concise formulation of the solution, different from Tchebychef's, would be as follows:—

To fit a polynomial of degree k, say $U_k(x)$, to data u_x with weights w_x, the weighted moments of u_x of orders 0, 1, 2, . . . , k are equated to the weighted moments of $U_k(x)$. Then $U_k(x)$ can be found determinantally, and if the resulting determinant-quotient, of which the numerator and denominator are bordered persymmetric moment-determinants, is

* References are given at the end of this paper.

expanded as a Schweins series, $U_k(x)$ appears expressed in terms of suitable orthogonal polynomials $Q_r(x)$. The standard results then follow readily from the orthogonal properties.

Practically, if the number of data is large and the weights are subject to no rule, the solution is laborious unless it is gone about in a systematic manner. The arbitrary nature of the weights stands in the way of any analytical sophistication; orthogonal polynomials emerge, but are not of great use; and the necessity of solving the moment equations cannot be circumvented. It becomes important, therefore, to obtain all the material for numerical solution with as much uniformity and as little tedium as possible; and this is our principal aim. In addition, since it is often advantageous to obtain directly the terminal value and differences $U(0)$, $\Delta U(0)$, $\Delta^2 H(0)$, . . . , from which the whole set of fitted values may be built up, we give a new solution in terms of factorial moments, which are easily obtained by repeated summation. The solving scheme is the same, whether ordinary or factorial moments are used, and has been devised with the aims (1) of employing one uniform type of operation throughout, (2) of obtaining not merely the final solving polynomial $U_k(x)$, in powers or factorials, but all corresponding polynomials $U_{k-r}(x)$ of lower degree complete at intermediate stages, (3) of finding S^2, the weighted sum-square of residuals, preliminarily at each stage.

2. Solution by Factorial Moments.

The solution of the problem in terms of factorial moments will be set out. The solution in terms of ordinary moments being quite analogous, an occasional reminder of the points of analogy will have the effect of presenting both forms of the solution at the same time.

Let u_x or $u(x)$, $x = 0, 1, \ldots, n-1$ denote the n data, w_x the weights, and $U_k(x)$ the polynomial of degree k to be fitted to u_x by Least Squares. Let us denote

$$x(x-1)\ldots(x-r+1) \text{ by } x^{(r)}, \quad \text{and} \quad x^{(r)}/r! \text{ by } x_{(r)},$$
$$\sum_{x=0}^{n-1}(x+p)^{(r)}w_x u_x \text{ by } M_{(r,\,p)}, \quad \text{and} \quad \sum_{x=0}^{n-1}(x+p)^{(r)}w_x \text{ by } W_{(r,\,p)}.$$

The last named are factorial moments of a slightly extended kind. Defining ordinary moments thus,

$$\sum_{x=0}^{n-1}x^r w_x u_x \text{ by } M_r, \quad \text{and} \quad \sum_{x=0}^{n-1}x^r w_x \text{ by } W_r,$$

we may throughout the following arguments substitute x^r, M_r, and W_r for $x^{(r)}$, $M_{(r,\,p)}$, and $W_{(r,\,p)}$, the transformed results being still valid.

It is required to determine $U_k(x)$ in such a way that

$$(1) \quad . \quad . \quad . \quad . \quad \sum_{x=0}^{n-1} w_x\{u_x - U_k(x)\}^2$$

shall be a minimum. Let $U_k(x)$ be expressed in factorials as

$$(2) \quad . \quad . \quad . \quad U_k(x) = a_0 + a_1 x + a_2 x^{(2)} + \ . \ . \ . \ + a_k x^{(k)}.$$

Substituting (2) in (1) and partially differentiating with respect to the coefficients a_r we obtain a set of $k+1$ relations, which can be modified at once by suitable linear combination in such a way as to give the following more convenient set:—

$$(3) \quad \begin{aligned} &\sum w_x\{a_0 + a_1 x + \ . \ . \ . \ + a_k x^{(k)}\} = \sum w_x u_x, \\ &\sum w_x\{a_0(x+1) + a_1(x+1)^{(2)} + \ . \ . \ . \ + a_k(x+1)^{(k+1)}\} = \sum (x+1) w_x u_x, \\ &\sum w_x\{a_0(x+2)^{(2)} + a_1(x+2)^{(3)} + \ . \ . \ . \ + a_k(x+2)^{(k+2)}\} = \sum (x+2)^{(2)} w_x u_x, \\ &. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad ., \end{aligned}$$

that is,

$$(4) \quad \begin{aligned} &a_0 W_{(0,\,0)} + a_1 W_{(1,\,0)} + \ . \ . \ . \ + a_k W_{(k,\,0)} = M_{(0,\,0)}, \\ &a_0 W_{(1,\,1)} + a_1 W_{(2,\,1)} + \ . \ . \ . \ + a_k W_{(k+1,\,1)} = M_{(1,\,1)}, \\ &. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \\ &a_0 W_{(k,\,k)} + a_1 W_{(k+1,\,k)} + \ . \ . \ . \ + a_k W_{(2k,\,k)} = M_{(k,\,k)}. \end{aligned}$$

The modified set is taken because the moments $W_{(r,\,p)}$, $M_{(r,\,p)}$ are obtained, except for numerical factors $r!$, together in a solid block in tables of repeated summation formed from the values w_x and $w_x u_x$ respectively, summation being, as usual in these cases, from the foot of each column. For example $W_{(r,\,p)}$ is the $(r-p+1)$th element from the top of the column $\sum^{r+1}$ of summations of w_x.

It is to be observed that the system of factorial moments $W_{(r,\,p)}$ which occurs above differs from the system of ordinary moments which occurs in the classical solution, in being not persymmetric nor even axisymmetric. This is a disadvantage which, to a certain extent, takes away from other advantages.

The description of the scheme for the solution of these moment equations will be taken up in § 4, in reference to worked examples. An expression for the weighted sum of squared residuals will now be obtained.

3. The Weighted Sum of Squared Residuals.

For the purposes of this section it is convenient to express $U_k(x)$ in terms of suitable orthogonal polynomials $Q_r(x)$, defined as having unity for coefficient of x^r, or $x^{(r)}$, and as satisfying the following relations:—

$$(1) \quad . \quad . \quad . \quad \sum (x+p)^{(s)} w_x Q_r(x) \begin{matrix} = 0, & s < r, \\ \neq 0, & s = r, \end{matrix}$$

which evidently hold also when $Q_s(x)$, or any polynomial of degree s, is substituted for $(x+p)^{(s)}$. We may therefore write

$$(2) \quad . \quad . \quad U_k(x) = c_0 + c_1Q_1(x) + c_2Q_2(x) + \ . \ . \ . \ + c_kQ_k(x),$$

where the coefficient c_k must be the same as the coefficient a_k of § 1 (2). Multiplying (2) by $w_xQ_k(x)$, summing and using (1), we have

$$(3) \quad . \quad . \quad . \quad . \ c_k\sum w_xQ_k{}^2x = \sum w_xu_xQ_k(x).$$

Hence the weighted sum-square of residuals, S^2, is given by

$$\begin{aligned} S^2 &= \sum w_x\{u_x - c_0 - c_1Q_1(x) - \ . \ . \ . \ - c_kQ_k(x)\}^2 \\ &= \sum w_xu_x{}^2 + \sum_{x=0}^{n-1}\sum_{r=0}^{k} w_x\{c_r^2Q_r{}^2 - 2c_ru_xQ_r(x)\} \\ (4) \quad . \quad . \quad . \quad &= \sum w_xu_x{}^2 - \sum_x\sum_r c_rw_xu_xQ_r(x), \quad \text{by (3).} \end{aligned}$$

It follows that the reduction in S^2 effected by passing from the fitted polynomial $U_{k-1}(x)$ to $U_k(x)$ is given by

$$(5) \quad . \quad . \quad S_{k-1}{}^2 - S_k{}^2 = c_k\sum w_xu_xQ_k(x) = a_k\sum w_xu_xQ_k(x).$$

Now $Q_r(x)$ can be written down at once from the orthogonal relations (1), in the form of a determinant-quotient,

$$(6) \quad Q_r(x) = \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(r-1,0)} & 1 \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(r,1)} & x \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ W_{(r,r)} & W_{(r+1,r)} & \cdots & W_{(2r-1,r)} & x^{(r)} \end{vmatrix} \div \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(r-1,0)} \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(r,1)} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{(r-1,r-1)} & W_{(r,r-1)} & \cdots & W_{(2r-2,r-1)} \end{vmatrix}.$$

For evidently this is a polynomial of degree r which has unity for coefficient of $x^{(r)}$, and it satisfies the relations (1) because, on putting (6) in the left member of (1), with $s<r$, and $p=0, 1, 2, \ . \ . \ . \ , r-1$, we obtain in every case a vanishing determinant in the numerator, the last column being identical with an earlier, the $(p+1)^{\text{th}}$. It follows that

$$(7) \quad a_k\sum w_xu_xQ_k(x) = a_k \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(k-1,0)} & M_{(0,0)} \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(k,1)} & M_{(1,0)} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ W_{(k,k)} & W_{(k+1,k)} & \cdots & W_{(2k-1,k)} & M_{(k,k)} \end{vmatrix} \div \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(k-1,0)} \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(k,1)} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{(k-1,k-1)} & W_{(k,k-1)} & \cdots & W_{(2k-2,k-1)} \end{vmatrix}.$$

But, solving for a_k from equations § 2 (4), we have also

$$(8) \quad a_k = \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(k-1,0)} & M_{(0,0)} \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(k,1)} & M_{(1,1)} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ W_{(k,k)} & W_{(k+1,k)} & \cdots & W_{(2k-1,k)} & M_{(k,k)} \end{vmatrix} \div \begin{vmatrix} W_{(0,0)} & W_{(1,0)} & \cdots & W_{(k,0)} \\ W_{(1,1)} & W_{(2,1)} & \cdots & W_{(k+1,1)} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{(k,k)} & W_{(k+1,k)} & \cdots & W_{(2k,k)} \end{vmatrix}.$$

Hence, from (5), we have

$$(9)\quad S_{k-1}^2 - S_k^2 = \begin{vmatrix} W_{(0,0)} & \cdots & W_{(k-1,0)} & M_{(0,0)} \\ W_{(1,1)} & \cdots & W_{(k,1)} & M_{(1,1)} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{(k,k)} & \cdots & W_{(2k-1,k)} & M_{(k,k)} \end{vmatrix}^2 \div \left\{ \begin{vmatrix} W_{(0,0)} & \cdots & W_{(k,0)} \\ & \ddots & \\ & & W_{(2k,k)} \end{vmatrix} \begin{vmatrix} W_{(0,0)} & \cdots & W_{(k-1,0)} \\ & \ddots & \\ & & W_{(2k-2,k-1)} \end{vmatrix} \right\},$$

and S^2 can be estimated by successively subtracting terms of this type, of increasing order, from the initial term $\sum w_x u_x^2$.

It is not difficult to prove that the three determinants which appear in the above expression (9) are unaltered in value by the substitution of ordinary for factorial moments. Indeed it is fundamental in this problem that, whatever origin we choose for x, and whatever system of polynomials (with unity for highest coefficient) and corresponding moments for the representation of $U_k(x)$, the *orthogonal polynomials, the moment determinant and its leading minors of every order remain invariant in numerical value.*

4. Worked Examples of the Methods.

The method of solution of the moment equations described below is applicable to any set of simultaneous equations, but is peculiarly convenient here, since all the determinants which appear in the expressions of § 3 for a_r and S^2 occur in conspicuous positions of the scheme.

The factorial moments $W_{(r,p)}$, $M_{(r,r)}$ are first computed by a process of repeated summation which will be described in connexion with the numerical examples.

The detached coefficients $W_{(r,p)}$, $M_{(r,r)}$ are then entered in the computing sheet, not in the relative positions which they occupy in § 2 (4), but *with rows and columns transposed.* To take the simplest case, the scheme for the equations

$$a_0 W_{(0,0)} + a_1 W_{(1,0)} = M_{(0,0)},$$
$$a_0 W_{(1,1)} + a_1 W_{(2,1)} = M_{(1,1)},$$

would be

		1	x	Δ
$W_{(0,0)}$	$W_{(1,1)}$	-1		
$W_{(1,0)}$	$W_{(2,1)}$		-1	
$M_{(0,0)}$	$M_{(1,1)}$			1,

where, as indicated, a *negative unit matrix* is placed to the right of the

transposed W-array, and a further $+1$ opposite the M-row. The array on the left will be called the (W, M) array.

The whole system is now condensed, stage by stage, by "pivotal" elements, *the pivot being always the leading element.* The theory * of such a reduction leads to the following facts:—

The leading element at any stage will be a leading minor of the W-determinant, and so will be used as a denominator of the expression § 3 (9) for the reduction in S^2. It will appear under the 1 in the last column at the next stage, and will be the W-determinant of the system corresponding to that stage. Under the several -1's will appear those minors of the (W, M) array which, divided by the W-determinant for this stage, will yield all the coefficients a_r in the factorial expansion of the solving polynomial $U_k(x)$ of corresponding degree.

Again, the element in the lower left-hand corner of the (W, M) array at any stage is the determinant which appears, squared, in the numerator of the expression § 3 (9) for the reduction in S^2. It will be found advantageous to compute the leading element, and this lower left-hand element, first of all at any stage, and thence to estimate S^2.

Example.

x	0	1	2	3	4	5	6	7	Σ
u	1	3	6	11	17	29	43	67	
w	1	4	2	3	2	1	3	5	21
wu	1	12	12	33	34	29	129	335	585
wu^2	1	36	72	363	578	841	5547	22445	29883

(*a*) By ordinary moments.

Step I. By the usual columnar process of multiplications and additions find the moments of w_x up to the $2k$th order, of $w_x u_x$ up to the kth.

We shall fit a cubic, taking $k=3$, and for convenience shall transfer to a new origin $x=4$. The moments are

$$\begin{aligned} W_r &: 21,\ -1,\ 121,\ -31,\ 1069,\ -751,\ 10981, \\ M_r &: 585,\ 1195,\ 3765,\ 9589. \end{aligned}$$

Step II. Enter the moments in a scheme of computation as described above, and proceed to condense by pivotal elements. It is best to retain most of the digits until near the last stage, when broader approximation can be adopted. The details of the computation will appear as follows:—

* Cf. *Proc. Edin. Math. Soc.*, vol. iii (2), 1932, pp. 207–219.

				1.	x.	x^2.	x^3.	Δ.
21	−1	121	−31	−1				
−1	121	−31	1069		−1			
121	−31	1069	−751			−1		
−31	1069	−751	10981				−1	
585	1195	3765	9589					1
	2540	−530	22418	−1	−21			
	−530	7808	−12020	121		−21		
	22418	−12020	229640	−31			−21	
	25680	8280	219504	585				21
÷ 21.								
		931020	−888060	14610	−530	−2540		
		−888060	3843756	−2682	22418		−2540	
		1649600	−864480	71980	25680			2540
	÷ 2540.							
			1098410688	4125024	8031864	−888060	−931020	
			259880160	16895340	9757040	1649600		931020
		÷ 931020.						
				$187816^{(11)}$	$926931^{(10)}$	$219407^{(10)}$	$259880^{(9)}$	$109841^{(10)}$

Dividing out by the values of Δ as shown in the last column at the various stages, we obtain the polynomials $U_k(x)$ as below:

$$U_0(x) : 585/21 = 27{\cdot}857.$$
$$U_1(x) : \{71980 + 25680(x-4)\}/2540 = 28{\cdot}339 + 10{\cdot}110(x-4).$$
$$U_2(x) : 18{\cdot}147 + 10{\cdot}480(x-4) + 1{\cdot}772(x-4)^2.$$
$$U_3(x) : 17{\cdot}099 + 8{\cdot}439(x-4) + 1{\cdot}997(x-4)^2 + 0{\cdot}2366(x-4)^3.$$

The residual error is computed from the pivotal and the other underlined corner elements * thus:

	S^2.	k.
$\sum wu^2 = 29883$		
$585^2/(1.21) = 16296$	13587	0
$25680^2/(21.2540) = 12363$	1224	1
$1649600^2/(2540.931020) = 1151$	73	2
$259880160^2/(931020.1098410688) = 66$	7	3

These values for S^2 will be found ((*b*), *infra*) to be in good agreement with the values computed from the fitted values of the polynomials, thus giving a check on accuracy.

(*b*) By factorial moments.

Step I. By successive summation, form the "reduced" factorial moments of w_x up to the 6th order, and of $w_x u_x$ up to the 3rd, summing from the foot of columns.

* Cut down to fewer digits than are shown.

[TABLE.

w.	Σ.	Σ^2.	Σ^3.	Σ^4.	Σ^5.	Σ^6.	Σ^7.	wu.	Σ.	Σ^2.	Σ^3.	Σ^4.
1	*21*	*104*	*370*	*1075*				1	*585*	*4120*	*17230*	*54679*
4	20	*83*	*266*	*705*	*1627*			12	584	3535	13110	37449
2	16	63	*183*	*439*	*922*	*1756*		12	572	2951	9575	24339
3	14	47	120	*256*	*483*	*834*	*1347*	33	560	2379	6624	14764
2	11	33	73	136	227	351	513	34	527	1819	4245	8140
1	9	22	40	63	91	124	162	29	493	1292	2426	3895
3	8	13	18	23	28	33	38	129	464	799	1134	1469
5	5	5	5	5	5	5	5	335	335	335	335	335
$r!$	1	1	2	6	24	120	720		1	1	2	6

Step II. Convert the requisite reduced moments, underlined above, into unreduced moments by multiplying by the proper $r!$, and enter the results in the solving scheme. Proceed as before with pivotal elements.

					1.	x.	$x^{(2)}$.	$x^{(3)}$.	Δ.
	21	104	740	6450	−1				
	83	532	4230	39048		−1			
	366	2634	22128	210720			−1		
	1536	11592	100080	969840				−1	
	585	4120	34460	328074					1
		2540	27410	284658	83	−21			
		17250	193848	2064420	366		−21		
		83688	965040	10459440	1536			−21	
		25680	290760	3116304	585				21
÷ 21.									
			931020	15870300	−23910	17250	−2540		
			7491120	130691376	−144984	83688		−2540	
			1649600	28828320	−30740	25680			2540
÷ 2540.									
				1098410688	17373888	−20199456	7491120	−931020	
				259880160	4260780	−1790160	1649600		931020
÷ 931020.									
					$177179^{(9)}$	$352635^{(10)}$	$-144847^{(9)}$	$259880^{(9)}$	$109841^{(10)}$

Dividing out by the values of Δ as before in (*a*), we have the following expressions for $U_k(x)$:—

$$U_0(x) : 27{\cdot}587.$$
$$U_1(x) : -12{\cdot}102 + 10{\cdot}110x.$$
$$U_2(x) : 4{\cdot}576 - 1{\cdot}923x + 3{\cdot}544x_{(2)}.$$
$$U_3(x) : 0{\cdot}1613 + 3{\cdot}2104x - 0{\cdot}2637x_{(2)} + 1{\cdot}4196x_{(3)}.$$

The computation of S^2 is identical with that given in (*a*).

It will now be shown that the values given in (*a*) for S^2 are in agreement with those found from the U's. Take for example $U_2(x)$. Building up from $U_2(0) = 4{\cdot}576$, $\Delta U_2(0) = -1{\cdot}923$, $\Delta^2 U_2(0) = 3{\cdot}544$, we obtain

U	4·58	2·65	4·27	9·44	18·15	30·40	46·20	65·54
$\lvert U - u \rvert$	3·58	0·35	1·73	1·56	1·15	1·40	3·20	1·46,

from which S^2 is found to be 72·6. Again, for $U_3(x)$ we build from

$U_3(0)=0{\cdot}1613$, $\Delta U_3(0)=3{\cdot}2104$, $\Delta^2 U_3(0)=-0{\cdot}2637$, $\Delta^3 U_3(0)=1{\cdot}4196$, obtaining

U	0·16	3·37	6·32	10·42	17·11	27·77	43·86	66·77
$\lvert U-u \rvert$	0·84	0·37	0·32	0·58	0·11	1·23	0·86	0·23,

from which S^2 is computed as 6·5. The values in (*a*) were 73 and 7.

(*c*) It may be noticed that the factorial moments used in (*b*), besides forming a non-symmetric system, are decidedly larger than the ordinary moments used in (*a*). We shall show by the following modified working * how smaller values can be obtained by transferring the origin to $x=4$.

Step I. Let a horizontal line be drawn across the table of summation, separating the rows opposite negative values of x from the rows opposite zero and positive values of x; and let summations be made from the ends of columns towards this line, as shown below. The required factorial moments are now the sums or differences of certain pairs of entries in columns of the scheme, in a manner which will be clear from the illustration.

	w.	Σ.	Σ^2.	Σ^3.	Σ^4.	Σ^5.	Σ^6.	Σ^7.	*wu.*	Σ.	Σ^2.	Σ^3.	Σ^4.
	1	1	1	1	*1*	*1*	*1*	*1*	1	1	1	1	*1*
−	4	5	6	*7*	*8*	*9*	*10*		12	13	14	*15*	
	2	7	*13*	*20*	*28*	*37*			12	25	*39*		
	3	*10*	*23*	*43*	*71*				33	*58*			
	2	*11*	*33*	*73*	*136*				34	*527*	*1819*	*4245*	*8140*
	1	9	22	*40*	63	*91*			29	493	1292	2426	3895
+	3	8	13	*18*	*23*	*28*	*33*		129	464	799	1134	1469
	5	5	5	5	*5*	5	*5*	5	335	335	335	335	335
	r!	1	1	2	6	24	120	720	·	1	1	2	6

Then

$W_{(0,0)}=11+10=21$, $W_{(1,1)}=33-13=20$, $W_{(2,2)}=(73+7)2=160$,
$W_{(3,3)}=(136-1)6=810$.

Also

$W_{(1,0)}=22-23=-1$, $W_{(2,1)}=(40+20)2=120$, $W_{(3,2)}=(63-8)6=330$, etc.,

and

$M_{(0,0)}=527+58=585$, $M_{(1,1)}=1819-39=1780$, $M_{(2,2)}=(4245+15)2=8520$,
$M_{(3,3)}=(8140-1)6=48834$.

Step II. The factorial moments as found in this way are entered in the scheme exactly as before. It will be seen that they are decidedly smaller than those in (*b*), being indeed of the same order as those in (*a*).

* The method is useful in many other connexions besides the present one.

				1.	x.	$x^{(2)}$.	$x^{(3)}$.	Δ.
21	20	160	810	−1				
−1	120	330	2208		−1			
122	−30	888	3840			−1		
−396	1008	−600	4320				−1	
585	1780	8520	48834					1
	2540	7090	47178	−1	−21			
	−3070	−872	−18180	122		−21		
	29088	−50760	411480	−396			−21	
	25680	85320	551664	585				21
÷ 21.								
		931020	4698060	14610	−3070	−2540		
		−3681120	−15578784	−46512	29088		−2540	
		1649600	9033120	71980	25680			2540
	÷ 2540.							
			1098410688	4125024	6212784	−3681120	−931020	
			259880160	16895340	11406640	1649600		931020
		÷ 931020.						
				$187816^{(11)}$	$117233^{(11)}$	$297372^{(10)}$	$259880^{(9)}$	$109841^{(10)}$

In the same manner as before we obtain the expressions for $U_k(x)$:—

$U_0(x)$: 27·857.
$U_1(x)$: $28{\cdot}339 + 10{\cdot}110(x-4)$.
$U_2(x)$: $18{\cdot}147 + 12{\cdot}252(x-4) + 3{\cdot}544(x-4)_{(2)}$.
$U_3(x)$: $17{\cdot}099 + 10{\cdot}673(x-4) + 5{\cdot}415(x-4)_{(2)} + 1{\cdot}4196(x-4)_{(3)}$,

and the fitted values are easily obtained by building from differences outwards from the origin. The computation of S^2 is identical with that of (*a*) and (*b*).

(*Observation.*—These methods can of course be applied to the particular case of *equally weighted* data, treated in the author's earlier paper, and by some may be thought preferable to the method there given, since tables of Tchebychef polynomials are not then required. For unit weights, $w_x = 1$, the ordinary moments are sums of powers of natural numbers, of which tables are available, while the reduced factorial moments are simply ordinary binomial coefficients, which are also available, and from which unreduced moments can be found at once. These can be entered in the last row of the first stage of the solving scheme, the work then proceeding as before.)

5. Case of Non-equidistant Data.

When the data are non-equidistant it is no longer possible to obtain factorial moments by summation. It is possible, indeed, to invent a calculus of "multiplied summation," inverse to "divided differencing," which yields a moment bearing to the ordinary factorial moment the same relation that factorial polynomials bear to the polynomials which appear in Newton's divided difference formula of interpolation, but too much

computation seems to be involved for practical use. It is best in this case, both for weighted and unweighted data, to use ordinary power moments and to express the graduating polynomial $U_k(x)$ in powers of x. When that is done the theory hardly differs from that of the preceding sections, and the scheme for solution is the same.

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II.—On Fitting Polynomials to Data with Weighted and Correlated Errors. By A. C. Aitken, M.A., D.Sc., University of Edinburgh.

(MS. received July 18, 1933. Read November 6, 1933.)

1. Notation.

This paper concludes the study of fitting polynomials by Least Squares, treated in two previous papers. The problem being concerned with the minimum of a positive definite quadratic form, it makes for conciseness to use matrix notation. We shall therefore adopt the following conventions:—

The n values of the variable x, of the data $u_0, u_1, \ldots, u_{n-1}$, of certain polynomials $q_r(x)$ entering into the solution, and so on, will be regarded compositely as *vectors*. They will be imagined as having their components or elements disposed in column array, but when written in full will be written horizontally, to save space, enclosed by curled brackets. Row vectors, when written out in full, will be enclosed by square brackets. In the shorter notation we shall write, for example, u, x for column vectors, u', x' for the row vectors obtained by transposition. The vectors occurring in the problem will be the following:—

The data . . .	$u \equiv \{u_0, u_1, \ldots, u_{n-1}\}$.
The smoothed values .	$v \equiv \{v_0, v_1, \ldots, v_{n-1}\}$.
The residuals . .	$\epsilon \equiv \{\epsilon_0, \epsilon_1, \ldots, \epsilon_{n-1}\}$, where $\epsilon_i = v_i - u_i$.
The values of x . .	$x \equiv \{0, 1, 2, \ldots, n-1\}$.
Certain polynomials .	$q_r \equiv \{q_r(0), q_r(1), \ldots, q_r(n-1)\}$.

Again, a quadratic form, for example $a_{11}x_1^2 + 2a_{12}x_1x_2 + a_{22}x_2^2$, since it is equal to the product

$$[x_1, x_2] \begin{bmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

in matrix (*i.e.* row into column) multiplication, will be denoted by $x'\mathrm{A}x$, whatever the number of variables, the square matrix A being axisymmetric. The partial derivatives of $\frac{1}{2}x'\mathrm{A}x$ with respect to the variables x constitute the vector $\mathrm{A}x$, or in row form $x'\mathrm{A}$.

The quadratic form to be made a minimum in the present problem is $\epsilon'\mathrm{W}\epsilon$, where the elements w_{ii}, w_{ij} in the symmetric matrix W are the "weights" attached to the terms ϵ_i^2, $2\epsilon_i\epsilon_j$. The matrix W is the

reciprocal of the matrix which has elements $r_{ij}\sigma_i\sigma_j$. The quadratic form $\epsilon'W\epsilon$ is positive definite, and its minimum is to be found subject to the condition that the elements v_i are values of a polynomial of degree k.

2. Orthogonal Polynomials.

Let us put

(1) $$v(x) = a_0 + a_1q_1(x) + a_2q_2(x) + \dots + a_kq_k(x),$$

where the polynomials $q_r(x)$ will be assigned later to fulfil certain requirements.

The expression to be made a minimum is

(2) $$\begin{aligned} S^2 &= \epsilon'W\epsilon \\ &= (v-u)'W(v-u). \end{aligned}$$

The minimal conditions are, that for each a_r

(3) $$\begin{aligned} 0 &= \tfrac{1}{2}\partial S^2/\partial a \\ &= (v-u)'W\left(\frac{\partial v}{\partial a}\right) \\ &= (v-u)'Wq_r, \qquad r = 0, 1, 2, \dots, k. \end{aligned}$$

Let us next introduce the following conditions, which resemble orthogonal conditions, except that a definite quadratic form takes the place of the more usual sum of squares:—

(4) $$q_r'Wq_s \begin{matrix} = 0, & r \neq s, \\ \neq 0, & r = s. \end{matrix}$$

The minimal conditions (3) then become

$$(a_rq_r - u)'Wq_r = 0,$$

i.e.

(5) $$a_r(q_r'Wq_r) = u'Wq_r,$$

from which the desired coefficients a_r may be found independently of each other, when once we have determined the values of $q_r(x)$. The expressions on either side of (5) will not be written out *in extenso*, for in the practical application it is easier to compute quadratic forms like $q_r'Wq_r$ and bilinear forms like $u'Wq_r$ as vector products $q_r'.Wq_r$ and $u'.Wq_r$.

Before determining the orthogonal polynomials $q_r(x)$ we shall obtain an expression for the residual quadratic error $\epsilon'W\epsilon$, or $(v-u)'W(v-u)$.

We have

$$\begin{aligned} (v-u)'W(v-u) &= v'Wv - 2u'Wv + u'Wu \\ &= \left(\sum a_rq_r\right)'W\left(\sum a_rq_r\right) - 2u'W\left(\sum a_rq_r\right) + u'Wu, \\ &= \sum a_r^2q_r'Wq_r - 2\sum a_ru'Wq_r + u'Wu, \quad \text{by (4)}, \end{aligned}$$

(6) $$= u'Wu - \sum a_ru'Wq_r, \quad \text{by (5)},$$

(7) $$= u'Wu - \sum a_r^2q_r'Wq_r.$$

The expressions (6) and (7) show how, when each a_r is found by means of (5), a_r may be multiplied again into $u'Wq_r$, the values so obtained being successively subtracted from $u'Wu$, and providing running estimates of the residual quadratic error before the values v are determined.

3. Determination of the q-Polynomials.

The polynomials $q_r(x)$ can be determined in succession from the orthogonal properties § 2 (4).

By convention, let

$$q_0(x)=1, \qquad q_0=\{1, 1, 1, \ldots, 1\}.$$

Next, if

$$q_1(x)=x-c_{01},$$

then since

$$q_1'Wq_0=0,$$

we have

(1) . . . . . $$c_{01}=x'Wq_0/q_0'Wq_0.$$

Next, assume

$$q_2(x)=x_{(2)}-c_{12}q_1(x)-c_{02}.$$

Then since

$$q_2'Wq_1=0, \qquad q_2'Wq_0=0,$$

we have

$$c_{12}=x_{(2)}'Wq_1/q_1'Wq_1,$$

(2) . . . . . $$c_{02}=x_{(2)}'Wq_0/q_0'Wq_0.$$

Proceeding in this way, we find in succession the polynomials $q_r(x)$ in the form

$$q_r(x)=x_{(r)}-c_{r-1,\,r}q_{r-1}(x)-c_{r-2,\,r}q_{r-2}(x)-\ .\ .\ .\ -c_{0r},$$

where

(3) . . . . . $$c_{sr}=x_{(r)}'Wq_s/q_s'Wq_s.$$

The values of the polynomials $q_r(x)$ serve now to determine the coefficients a_r from § 2 (5), the values v and the residual quadratic error.

The order of computation will now be illustrated by an actual worked example.

4. Numerical Example.

To fit a cubic polynomial to the data

x	0	1	2	3	4	5	6
u	7	1	3	21	59	127	251,

the array of weights w_{ij} in the quadratic form $\epsilon'W\epsilon$ being given by the matrix

$$W = \begin{bmatrix} 1 & \cdot 271 & \cdot 566 & \cdot 202 & -\cdot 142 & \cdot 250 & -\cdot 446 \\ \cdot 271 & 1 & \cdot 447 & 0 & -\cdot 011 & \cdot 131 & -\cdot 627 \\ \cdot 566 & \cdot 447 & 1 & \cdot 114 & \cdot 353 & \cdot 047 & -\cdot 320 \\ \cdot 202 & 0 & \cdot 114 & 1 & \cdot 138 & \cdot 164 & \cdot 227 \\ -\cdot 142 & -\cdot 011 & \cdot 353 & \cdot 138 & 1 & \cdot 246 & \cdot 511 \\ \cdot 250 & \cdot 131 & \cdot 047 & \cdot 164 & \cdot 246 & 1 & \cdot 209 \\ -\cdot 446 & -\cdot 627 & -\cdot 320 & \cdot 227 & \cdot 511 & \cdot 209 & 1 \end{bmatrix}.$$

Summing the rows of W, we find

$$Wq_0 = \{1\cdot 701 \quad 1\cdot 211 \quad 2\cdot 207 \quad 1\cdot 845 \quad 2\cdot 095 \quad 2\cdot 047 \quad 0\cdot 554\}.$$

Hence

$$q_0'Wq_0 = 11\cdot 660, \quad x'Wq_0 = 33\cdot 099, \quad x_{(2)}'Wq_0 = 49\cdot 092, \quad x_{(3)}'Wq_0 = 41\cdot 775, \quad u'Wq_0 = 581\cdot 11.$$

Hence

$$q_1(x) = x - \frac{33\cdot 099}{11\cdot 660} = x - 2\cdot 8387,$$

whence

$$q_1 = \{-2\cdot 8387 \quad -1\cdot 8387 \quad -0\cdot 8387 \quad 0\cdot 1613 \quad 1\cdot 1613 \quad 2\cdot 1613 \quad 3\cdot 1613\},$$

and

$$Wq_1 = \{-4\cdot 8136, \ -4\cdot 6947, \ -3\cdot 7490, \ 0\cdot 7246, \ 3\cdot 4579, \ 2\cdot 1442, \ 6\cdot 9304\}.$$

Hence

$$q_1'Wq_1 = 56\cdot 1167, \quad x_{(2)}'Wq_1 = 144\cdot 570, \quad x_{(3)}'Wq_1 = 174\cdot 606, \quad u'Wq_1 = 2181\cdot 44.$$

Hence

$$q_2(x) = x_{(2)} - \frac{144\cdot 570}{56\cdot 1167}q_1(x) - \frac{49\cdot 092}{11\cdot 660}$$
$$= x_{(2)} - 2\cdot 57624q_1(x) - 4\cdot 2103,$$

whence

$$q_2 = \{3\cdot 1029, \ 0\cdot 5266, \ -1\cdot 0496, \ -1\cdot 6258, \ -1\cdot 2021, \ 0\cdot 2217, \ 2\cdot 6454\},$$

and

$$Wq_2 = \{1\cdot 3694, \ -0\cdot 7181, \ -0\cdot 5038, \ -0\cdot 6477, \ -0\cdot 8370, \ 1\cdot 0076, \ 0\cdot 3302\}.$$

Hence

$$q_2'Wq_2 = 7\cdot 5558, \quad x_{(3)}'Wq_2 = 12\cdot 6843, \quad u'Wq_2 = 155\cdot 217.$$

Hence

$$q_3(x) = x_{(3)} - \frac{12\cdot 6843}{7\cdot 5558}q_2(x) - \frac{174\cdot 606}{56\cdot 1167}q_1(x) - \frac{41\cdot 775}{11\cdot 660}$$
$$= x_{(3)} - 1\cdot 6788q_2(x) - 3\cdot 1115q_1(x) - 3\cdot 5828,$$

whence

$$q_3 = \{0\cdot 0407, \ 1\cdot 2543, \ 0\cdot 7889, \ -0\cdot 3553, \ -1\cdot 1781, \ -0\cdot 6799, \ 2\cdot 1397\},$$

and

$$Wq_3 = \{-0\cdot 2016, \ 0\cdot 2003, \ 0\cdot 1996, \ -0\cdot 0455, \ -0\cdot 0421, \ -0\cdot 3692, \ 0\cdot 2579\}.$$

Hence

$$q_3'Wq_3 = 1\cdot2691, \qquad u'Wq_3 = 13\cdot7930.$$

Thus finally

$$\begin{aligned} a_0 &= 581\cdot11/11\cdot660 = 49\cdot838, \\ a_1 &= 2181\cdot44/56\cdot1167 = 38\cdot873, \\ a_2 &= 155\cdot217/\ 7\cdot5558 = 20\cdot543, \\ a_3 &= 13\cdot7930/\ 1\cdot2691 = 10\cdot868. \end{aligned}$$

Using the values of $q_1(x)$, $q_2(x)$, $q_3(x)$, found earlier, we thus obtain

u	7	1	3	21	59	127	251
v	3·674	2·812	4·247	18·848	57·483	131·019	250·326
ϵ	−3·326	1·812	1·247	−2·152	−1·517	4·019	−0·674.

These residuals give

$$W\epsilon = \{-1\cdot044,\ 2\cdot433,\ -0\cdot202,\ -2\cdot362,\ -0\cdot277,\ 2\cdot617,\ -1\cdot149\},$$

and so

$$\epsilon'W\epsilon = 24\cdot4.$$

The value thus found for the residual quadratic error is in fair agreement with that found from § 2, (6), as follows:—

$$Wu = \{-75\cdot363,\ -137\cdot15,\ -43\cdot721,\ 108\cdot70,\ 221\cdot46,\ 199\cdot44,\ 307\cdot75\},$$

and so

$$u'Wu = 117{,}127.$$

Multiplying the a_r's each by its numerator and subtracting from $u'Wu$, we have

		Residual Quadratic Error.
	117127	
Const.	28961	88166
St. line	84799	3367
Parabola	3189	178
Cubic	150	28,

which shows how the quadratic error is reduced by fitting.

For non-equidistant data a similar procedure can be adopted, naturally a little more laborious, since in the place of

$$x = \{0,\ 1,\ 2,\ .\ .\ .,\ n-1\}$$

we have

$$x = \{x_0,\ x_1,\ x_2,\ .\ .\ .,\ x_{n-1}\}.$$

In such a case it is more convenient in general to use x^r in place of $x_{(r)}$ in constructing the q-polynomials.

(*Issued separately November* 29, 1933.)

III.—**The Cruciform Muscle of Lamellibranchs.** By **Alastair Graham,** M.A., B.Sc. (From the Department of Zoology, the University of Sheffield.) *Communicated by* Professor J. H. Ashworth, F.R.S. (With Six Text-figures.)

(MS. received September 11, 1933. Read November 6, 1933.)

In 1900 von Ihering directed attention to the presence in certain Lamellibranchs of a special muscle lying in the posterior portion of the ventral mantle edge, close to the inner end of the inhalent siphon. This muscle consisted of two strands, each running diagonally from an origin on one valve to be inserted on the other, and crossing one another in the mid-ventral line so as to form a muscular apparatus with the appearance of a St Andrew's cross. He regarded this cruciform muscle as a specially differentiated group of fibres belonging to the pallial edge, acting as an accessory adductor muscle, a point of view in which he has been followed by all subsequent observers. To this von Ihering added the speculation that it had been by some similar process of specialisation of marginal pallial muscle fibres that the two other true adductor muscles of Lamellibranchs had originated.

In a series of papers describing the anatomy of various members of the Solenidæ, Bloomer (1903*a*, 1903*b*, 1905*a*, 1905*b*, 1907, 1912) recorded the occurrence of a cruciform muscle in the subfamily Solecurtinæ. It was found in the typical cross shape in the majority of the members of that group—*Solecurtus*, *Azor*, *Tagelus rufus*, and *T. gibbus*, but in *T. divisus*, a species which Ghosh (1920) has placed in the subgenus *Subtagelus*, the muscle was present in the modified form of a single rounded muscular strand running straight across the middle line from one valve to the other. This condition Ghosh regards as the primitive one for the subfamily, and that from which the more usual cross-shaped type has been evolved. Bloomer (1911) extended his researches to the family Psammobiidæ, and described the existence of a cruciform muscle in four species of *Psammobia*. Although this animal belongs to a different family the muscle had apparently a complete superficial resemblance to that of the Solenidæ.

The next advance in our knowledge of the cruciform muscle came from Hoffmann (1914) as a result of a more thorough examination of the anatomy and histology of *Tagelus dombeyi*, a species which had been

already investigated by Bloomer (1905*a*) under the name *Solecurtus dombeyi*, and has since been placed in a new subgenus *Solecurtellus* specially erected for it by Ghosh (1920). On each side, in the posterior half of the musculus cruciformis of this mollusc, Hoffmann noted the presence of a pallial sense organ, which he described as consisting of a pit lined by a ciliated epithelium and overlying a layer of ganglion cells, from which a small nerve passed to the posterior pallial nerve. The ciliated pit was anteriorly in communication with one of the pallial blood sinuses; posteriorly it ended blindly within the muscle. Hoffmann regarded this as a sensory organ for the perception and regulation of the blood-pressure in the siphons.

In the course of other work I have had occasion to investigate the anatomy of several Lamellibranchs, all possessing the cruciform muscle, and in so doing I have observed that the description given by Hoffmann of the condition in *Tagelus dombeyi* is different in important respects from what appears to be the typical structure of this organ, and, although I have not been able to examine that particular species, I am convinced from comparison with other types that he is in error in some points. Indeed, he admits himself in his description that the nerve supply of the organ "ich an meinem Material nur an einer Seite mit Sicherheit habe feststellen können"—as if either his material were at fault or his sections incomplete.

Donax vittatus, *Tellina crassa*, *Macoma balthica*, *Scrobicularia plana*, *Gari tellinella*, and *Solecurtus scopula*, the names used being those in Winckworth's recent list (1932), have been examined in this connection. It will be noticed that these are representative of five distinct families, the Donacidæ, Tellinidæ, Semelidæ, Asaphidæ, and Solenidæ.

Gari tellinella.

In this species occurs what is perhaps the most simple arrangement of the cruciform muscle with its associated sense organs, and it may be described as the type of which the others present slight modifications.

The mantle folds (see fig. 1) are thickened at their free ventral margin (*p.m.*), and projecting from them into the pallial cavity, running parallel with and a little way within the thickened edge, is an inner longitudinal fold or velum (*v.*). Slightly anterior to the point of origin of the ventral siphon (*v.s.*), and immediately ventral to the bay in which waste matter or rejected food material is collected prior to ejection from the mantle cavity, the inner longitudinal folds of the right and left mantle edges fuse, forming a horizontal partition (*p.*) which separates the pallial cavity from

an external space into which the two siphons may be withdrawn, and which may therefore be called the siphonal space (*s.s.*). The thickened margins of the two mantle folds remain separate. The partition is confluent on the posterior aspect with the ventral wall of the inhalent siphon (*v.s.*). It is just at this point that the cruciform muscle is developed. In the mantle on each side, ventral to the velum and a little anterior to

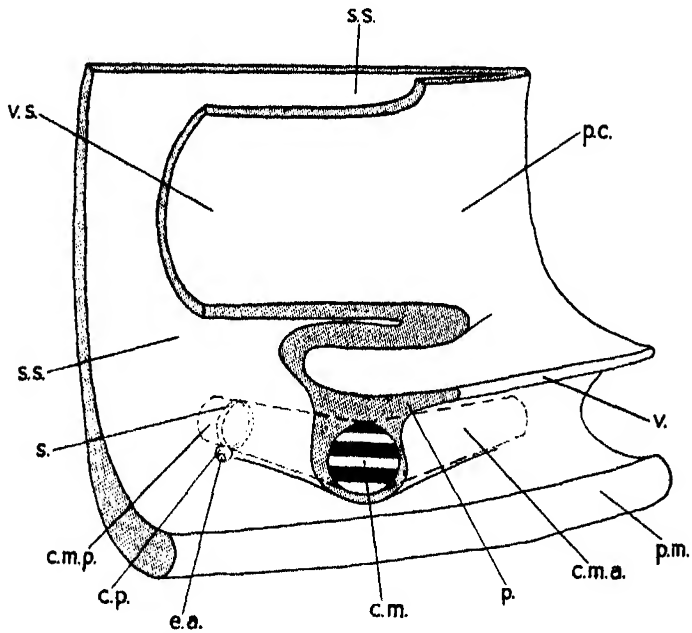

FIG. 1.—*Gari tellinella.* Diagrammatic representation of the relations of the cruciform muscle and its sense organ. A piece of tissue consisting of a portion of the left mantle lobe, the left half of the proximal end of the inhalent siphon, and the left half of the cruciform muscle has been isolated. All cut surfaces are stippled except the crossing of the two arms of the muscle, where one is shown white, the other in solid black. *c.m.*: cruciform muscle crossing; *c.m.a.*: anterior portion of cruciform muscle; *c.m.p.*: posterior portion of cruciform muscle; *c.p.*: ciliated pit; *e.a.*: external aperture of sense organ; *p.*: partition formed by fused vela; *p.c.*: mantle cavity; *p.m.*: edge of mantle; *s.*: intramuscular slit; *s.s.*: siphonal space; *v.*: velum; *v.s.*: ventral siphon. × about 12.

the point of fusion of the two vela, there is inserted on each valve a bundle of muscle fibres (*c.m.a.*), circular in transverse section, which lies in a blood sinus. From their origins on the valves of the shell the two muscle bundles, one on each side, pass backwards and towards the middle line, entering as they do so the partition formed by the inner longitudinal folds; in the middle line the two muscles meet (*c.m.*) and the fibres of which they are composed interdigitate, so that each muscle pierces right through the other. Each now, continuing in the same direction as before, passes

further backwards, but having crossed over the middle line laterally, runs out of the partition into the mantle fold once again. There the muscle becomes attached to the medial wall of a slit-like space (*s.*) which stretches completely across the muscle and is, in fact, of exactly the same shape and size as the transverse section of the muscle. All the fibres which arise from the opposite valve at their other extremity are inserted on the wall of this slit.

From the external wall of the slit a second portion of the strand (*c.m.p.*) runs to the valve, to which the fibres are attached. This posterior section of the muscle is very short in comparison with the anterior, being in the ratio of one to nine in *Gari tellinella*. The muscle fibres of this apparatus, therefore, are arranged on each side in two sets, one running from the shell a very short distance to the slit, the other running from the slit some considerable way across the pallial cavity to their origin further forwards on the valve of the other side.

The slit, which thus separates each half of the muscle into two portions, is closed everywhere except postero-ventrally, where it communicates by means of a small aperture with a somewhat spherical cavity (*c.p.*) lying in the connective tissue and blood sinuses of the mantle on the medial side of the muscle. This cavity opens by a second aperture (*e.a.*) directly to the exterior, the opening being at the summit of a minute elevation raised a few microns above the general body-surface. The cavity in which this aperture lies, it will be remembered, is the space into which the siphons may be withdrawn, and is quite external to the body of the animal and to the mantle cavity.

Surrounding the spherical pit on all sides except that on which it abuts against the muscle is a mass of nervous tissue forming a small ganglionic body. A small branch puts this into connection with the posterior pallial nerve, and so with the visceral ganglion. The relations of the slit, the ciliated pit, and the siphonal space are shown in fig. 2.

The intramuscular slit is lined by a squamous epithelium (fig. 3A, *s.e.*) composed of cells averaging between 2 and 3 μ in height. They contain oval nuclei which tend to stain darkly, and the cytoplasm is dense. The edge of the cell facing the cavity is very definite and is devoid of cilia. The epithelium rests on a thick layer of connective tissue (*c.t.*) in which many fine fibrillæ may be distinguished, running in a direction at right angles to the layer of surface cells. In this thick bed of connective tissue the fibres of the cruciform muscle (*c.m.*) end.

An approximately circular aperture, with a diameter of about 25 μ, connects the slit with the ciliated pit. The cells which form the epithelial lining of this pit (fig. 3B) reach a height, on the average, of about

6 μ. They are composed of rather dense cytoplasm, although they are much more highly vacuolated than the cells lining the intramuscular slit. Their nuclei are larger and do not stain so darkly as do those of the cells of that region. The most characteristic difference is the fact that

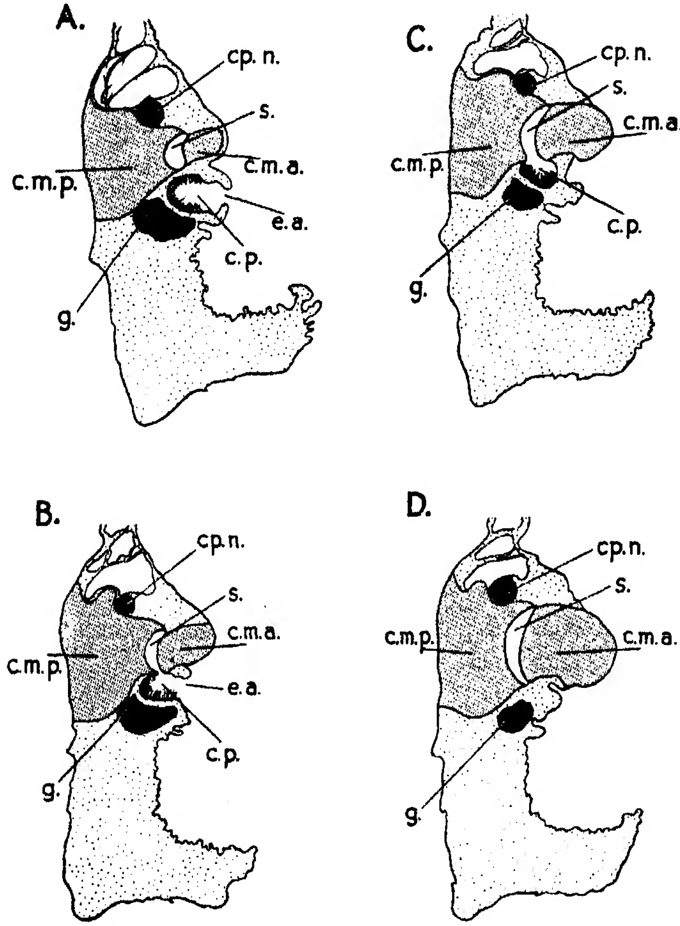

FIG. 2.—*Gari tellinella.* Selected transverse sections through the sense organ of the cruciform muscle. A = 11th, B = 13th, C = 14th, D = 16th sections from series, numbered from the posterior end. *c.m.a.*: anterior portion of cruciform muscle; *c.m.p.*: posterior portion of cruciform muscle; *c.p.*: ciliated pit; *cp.n.*: pallial nerve; *e.a.*: external aperture of sense organ; *g.*: ganglion; *s.*: intramuscular slit. × 88.

they bear a dense covering of cilia which may reach a length equal to two or three times the height of the cell that bears them. The cells rest on a basement membrane overlying a thick layer of connective tissue; beneath this lies the small ganglion, especially well developed below the ventral

wall of the pit. In the epithelium and in the underlying connective tissue lie mucous cells, opening, in the latter case, by means of long and fine ducts which pierce the epithelium.

The ganglion consists mainly of rather elongated triangular cells about 12–15 μ in length and 3–4 μ in breadth, with the base of the triangle proximal, the apex near the epithelium. The cells are arranged in about half a dozen layers, and it is easy to trace minute fibrillæ (*f.g.c.*) passing from the apices of the cells through the subepithelial layer of connective tissue and into the ciliated epithelium itself. Once they are

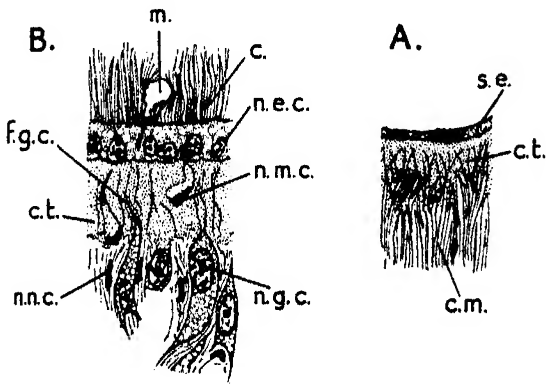

FIG. 3.—*Gari tellinella.* A. Part of a section through the slit, with the attachment of the cruciform muscle. B. Part of a section through the ciliated pit and ganglion. *c.*: cilia; *c.m.*: cruciform muscle fibres; *c.t.*: connective tissue; *f.g.c.*: fibrils of ganglion cell; *m.*: mucus extruded into pit; *n.e.c.*: nucleus of epithelial cell; *n.g.c.*: nucleus of ganglion cell; *n.m.c.*: nucleus of mucous cell; *n.n.c.*: nucleus of neuroglia cell; *s.e.*: epithelium of slit. × 800.

within that, however, it becomes impossible to trace the fibrils any further. Lying among the nerve cells composing the ganglion occur occasional connective tissue or neuroglia cells which it is possible to distinguish by means of their nuclei (*n.n.c.*). Those of the ganglion cells (*n.g.c.*) are large, round, and lightly staining, and each contains a distinct nucleolus; those of the neuroglia cells are small, elongated, and stain darkly. From the ganglion cells axones pass laterally and dorsally to form a small nerve running to the posterior pallial nerve.

Scrobicularia plana.

In all essentials the arrangement of the cruciform muscle found in this species is the same as in *Gari tellinella*, but there are differences in detail.

The ciliated pit (fig. 4, *c.p.*) lies deep within the mantle folds at the posterior end of the muscle, and communicates with the external siphonal space by means of a long duct (*d.*) measuring 0·7 mm. in the specimen sectioned. The duct has one prominent convolution near its external opening which gives to it something of the shape of a question mark or button-hook. It opens on the posterior surface of a salient spherical

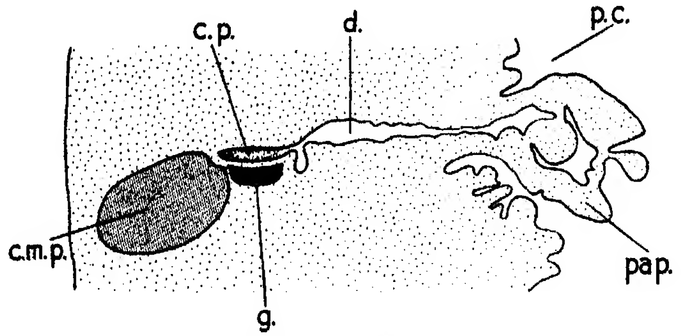

FIG. 4.—*Scrobicularia plana.* Transverse section through the sense organ of the cruciform muscle. *d.*: duct leading from mantle cavity to ciliated pit; *pap.*: papilla on which duct opens; *p.c.*: mantle cavity. Other letters as in fig. 2. × 88.

papilla (*pap.*). The mouth of the duct is lobed and small processes project into it, presumably to prevent the ingress of solid particles. No sphincter muscle could be detected.

The duct connecting the pit with the exterior is lined by cells similar to those forming the general covering of the edges of the mantle folds; they attain a height of 12 μ, contain vacuolated cytoplasm and a round, lightly staining nucleus which possesses a nucleolus. At their outer edge is a thickened layer of dense cytoplasm, with different staining reactions from the deeper cytoplasm. The cells rest on the thick connective tissue masses which here compose the bulk of the pallial folds.

The structure of the ciliated pit and ganglion is as in *Gari*. The intramuscular slit shows a slight difference in that the cells lining it differ from those of the ciliated pit only in lacking a covering of cilia.

Tellina crassa.

In the structure of the cruciform muscle and its associated sense organs this Lamellibranch resembles *Gari* very closely. The ciliated pit opens directly to the exterior, but is more elongated and less spherical in form than in that species.

Macoma balthica.

The general relations of the musculus cruciformis in *Macoma* are similar to those already described. There is a special resemblance to the

condition met with in *Scrobicularia* as the ciliated pit lies at the inner end of a short duct which opens to the siphonal space at the apex of a small, pointed papilla. The duct is lined with cells similar to those covering the mantle edge. The ciliated pit (fig. 5, *c.p.*) is rather elongated, and, with its underlying ganglion, it projects into the posterior portion of the muscle, tending to split it into dorsal and ventral halves. The nerve supply of the organ also passes through the muscle.

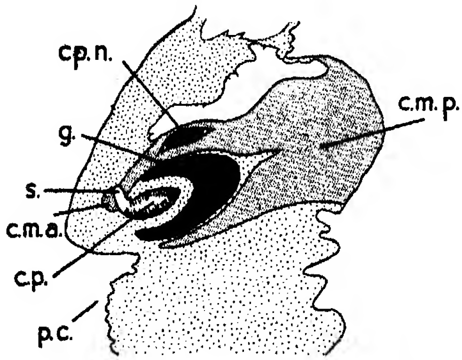

FIG. 5.—*Macoma balthica.* Transverse section through the sense organ of the cruciform muscle. Letters as in figs. 2 and 4. × 88.

Solecurtus scopula.

A more extensive fusion of the ventral margins of the pallial folds occurs in this mollusc than in any of those that have been so far described, with the result that the cruciform muscle lies a greater distance behind the posterior end of the ventral gape of the mantle. It appears as a narrow cross of muscular fibres embedded in the mantle, considerably more extended from side to side than in the other genera. An essential similarity of structure prevails, however, between this Lamellibranch and *Tellina crassa* in particular, from which it differs only very slightly as regards the cruciform muscle. The ciliated pit opens, not directly to the exterior as in that form, but into an outer chamber, and that, in its turn, opens to the siphonal space at the apex of a slight rounded elevation. The chamber, like the duct of *Scrobicularia* and *Macoma*, is lined by cells similar to those of the external surfaces of the mantle. Its walls are flung into several thin folds which project as lamellæ into the lumen.

Donax vittatus.

This species has been treated out of order as it shows an important difference from the five previous examples and resembles *Tagelus dombeyi* as described by Hoffmann. The position and the arrangement of the complex is as in the other forms, but the ciliated pit (fig. 6, *c.p.*) opens, not to the exterior, but to a small cavity (*c.*) which is completely separated off from any other. It has no connection with the exterior and no direct communication with the pallial blood sinuses of the mollusc, although, as it is separated from them only by a thin epithelial and connective

tissue wall, it must be in close osmotic relation with them. The ciliated pit opens anteriorly to the intramuscular slit, and postero-ventrally

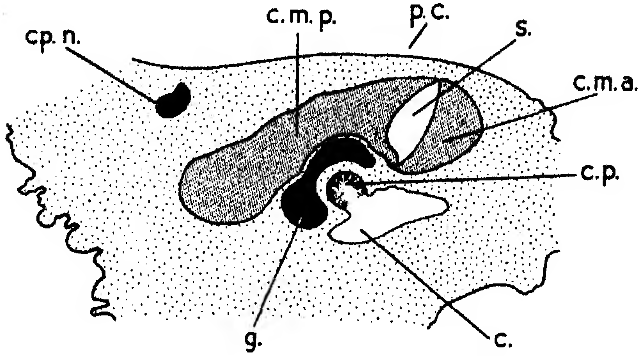

FIG. 6.—*Donax vittatus.* Transverse section through the sense organ of the cruciform muscle. *c.*: closed cavity into which the ciliated pit opens. Other letters as in fig. 2. × 88.

it is in wide communication with the chamber. This enclosed space is lined by a very low squamous epithelium, the cells of which possess oval, darkly staining nuclei.

DISCUSSION.

Of the six species of Lamellibranchs here described five agree very closely as regards the structure of the cruciform muscle with its associated sense organs, while the sixth differs from these only in one point, albeit an important one. It is not credible that an organ showing such a degree of complexity and similarity throughout several distinct families should have been evolved without serving some useful end.

The function which von Ihering (1900) suggested for the muscle—that of a secondary adductor, helping to pull the pallial edges together—may be dismissed at once. It is impossible to imagine that the complicated mechanism which is associated with the muscle would be present if that were the sole reason for its existence. There is no necessity for a pallial adductor to be cross-shaped—a simple transverse muscle-band would be equally or more efficient in approximating the two edges.

If all the details of the structure be taken into consideration, it would seem that the most feasible suggestion as to the function of the organ is to regard it as a chemoreceptor, a means of testing the purity or the reaction of the water in which the bivalve finds itself. The method of working we may imagine to be somewhat as follows: The anterior ends of the anterior portion of the cruciform muscle are inserted on the valves, and so likewise are the posterior ends of the posterior portions. The

posterior ends of the anterior sections, and the anterior ends of the much smaller posterior parts, end in the connective tissue lying around the intramuscular slits. When these muscles contract they will pull the two walls of the slits apart, and so increase the volume of the space enclosed by them. To fill up this increased space, water will pass in from the ciliated pits to the intramuscular slits and, again, from the siphonal space into the ciliated pits. This siphonal space, from which the pits fill themselves on the contraction of the muscles, is a truly external space, much more so than is the mantle cavity. The effect of contracting the cruciform muscle, therefore, is to cause a current of water, drawn from a much more external source than any to which an abdominal sense organ or osphradium could react, to pass over the epithelium of the ciliated pit. That will stimulate the sensory nerve-endings which lie in and protected by the epithelium, and nerve impulses may pass up the posterior pallial nerve to the visceral ganglion, where they may evoke the appropriate response.

The last bivalve described in this paper, *Donax vittatus*, agrees with Hoffmann's (1914) description of *Tagelus dombeyi* in possessing a cruciform muscle of which the sense organ opens into a completely enclosed space. Hoffmann stated that in *Tagelus* the ciliated pit opened widely into a blood sinus; however, I feel sure that he has described a faulty section in which the very thin and delicate wall separating the chamber from the pallial blood sinuses has been torn away, and that *Tagelus* really presents the same condition as *Donax*. He also remarks that the intramuscular slit is posterior, the ciliated pit anterior. In all the forms here examined the conditions are reversed, so that he may again have been mistaken on this point. It appears rather difficult to reconcile this arrangement with the view just stated—that the structure is a water-testing mechanism—as in these two cases the sensory epithelium can never come into contact with any external water to test. Under such circumstances one might perhaps expect that the organ would show some signs of having undergone degeneration, but so far as may be made out in sections of *Donax* it appears to be quite as well developed as in those forms in which the ciliated pit opens to the exterior.

If it is difficult to accept this organ in *Donax* and *Tagelus* as a water-testing mechanism, it is not any easier to agree with Hoffmann's view that its function is the perception and the regulation of the blood-pressure in the neighbourhood of the siphons. Presumably this means that the organ is employed by the bivalve to measure the amount of blood either already present in the siphons or else required or available to protrude them from the siphonal space. No other reason, at least, why the mollusc should require to be acquainted with the blood-pressure or be capable of

controlling it in this region comes readily to mind. But the cruciform muscle and its sense organs are not in a situation which makes this possible—only ventrally do they lie in a position where they could either estimate or control the pressure of blood in the siphons, and these, laterally, are in free and untrammelled communication with the capacious pallial sinuses. This view fails, too, to take into consideration the much more common structure of the apparatus in related genera where the slit is in connection with the outside sea-water; and it also neglects the fact that by far the great majority of Lamellibranchs manage to be aware of and to control the flow of blood to their siphons without possessing a cruciform muscle or the sense organ that accompanies it.

The more widespread occurrence of the open condition of the ciliated pit justifies us in regarding that as the primitive condition, and in accepting the closed state as secondary. We might perhaps regard the conditions seen in *Macoma* and *Scrobicularia* as being intermediate between the open pit of *Gari* and *Tellina* and the completely closed condition encountered in *Donax* and *Tagelus*. In *Macoma* the pit lies at the bottom of a short duct, in *Scrobicularia* at the inner end of a duct of some length, and, when the development of the enclosed pits is known, it will probably be found that they pass through an early open condition. But just what the significance of this step is, is no easy question to answer, and it seems impossible to link it with any factor in the life of the various animals. What the rôle of the cruciform muscle may be in those forms which possess it in its modified form is difficult to imagine, and it will serve no useful purpose to impute any definite function to it until further information is available.

The structure of this cruciform muscle complex bears upon still another point. It has already been observed that the examples which have been investigated belong to five different families of Lamellibranchs. In the classification of the group given by Pelseneer (1892), and also in that of Ridewood (1903), the Tellinidæ, Scrobiculariidæ (=Semelidæ), and the Donacidæ are grouped in the suborder Tellinacea, the other two families, the Psammobiidæ (=Asaphidæ) and the Solenidæ, being placed in the Myacea. It is surely improbable that an organ of such complexity as the cruciform muscle should have been evolved twice within the Lamellibranchs. Yet such is precisely what the above classification would suggest. The presence of the muscle in two families of the Myacea implies a much closer kinship with the Tellinacea than is there suggested, and these families ought to be removed from that group. This has, indeed, been done in the classification given by Thiele (1926), where the Tellinacea, consisting of the families Tellinidæ, Semelidæ, Psammo-

biidæ, and Donacidæ, and the Solenacea, which contains the sole family Solenidæ, are grouped together in the suborder Hemidapedonta. The family Solenidæ, including the more typical razor-shells and the genera related to *Solecurtus*, still appears to be an unnatural group, and a further improvement on Thiele's arrangement would be to revert to the earlier usage of d'Orbigny, as recorded by Forbes and Hanley (1853), and split the Solenidæ into two families as follows:—

SOLENACEA.

Family *Solenidæ*.—In this fall two subfamilies, the Soleninæ, including the more characteristic genera, and a more primitive group the Novaculinæ.

Subfamily *Soleninæ*.—These possess an elongated body of little height, laterally compressed, frequently with a fourth pallial aperture. The foot is long and cylindrical. There is no siphonal space posteriorly. There is no trace of a cruciform muscle or of its sense organ. The retractor pedis anterior muscle has two heads, both inserted on the shell valves. The protractor pedis muscle is feebly developed or absent. The intestine arises from the stomach quite independently of the style-sac.

Subfamily *Novaculinæ*.—The body is short and broad, not compressed. The mantle folds fuse to form a flat ventral surface without a fourth aperture. The foot is almost cylindrical, but also short and stout The siphons may be withdrawn into a siphonal space. There is no trace of a cruciform muscle or of its sense organ. The retractor pedis anterior muscle has two heads, both inserted on the shell valves. The protractor pedis muscle is absent. The intestine arises from the stomach quite independently of the style-sac.

Family *Solecurtidæ*.—The body is short and broad, not compressed. The mantle folds fuse to form a flat ventral surface without a fourth aperture. The foot is linguiform and laterally compressed. The siphons may usually be withdrawn into a siphonal space. A cruciform muscle complex is present. The retractor pedis anterior muscle has one head only. The protractor pedis muscle is usually well developed. The intestine arises from the stomach conjoined with the style-sac.

The exact relationships of these three groups of Lamellibranchs to each other and to the Tellinacea (of Thiele, not of Pelseneer) must be made more exact on the basis of more extended knowledge of the animals belonging to them. The Novaculinæ, as Ghosh (1920) pointed out when he established the group, are more primitive than either the Solenidæ or the Solecurtidæ. The position of the latter family must still be regarded as doubtful. Thiele placed them with the Solenidæ in the

Solenacea. An examination of the family characters given above, however, shows that they contrast with the Solenidæ in many points, and the feature of special interest is that upon all of these they agree with the family Psammobiidæ of the Tellinacea. Whether they are to fall in with these or to remain with the Solenidæ can be decided only when the structure of both is more fully examined.

Summary.

1. The cruciform muscle of Lamellibranchs has always associated with it special sense organs.

2. These consist on each side of a slit, separating the halves of the muscle into two portions, in communication with a ciliated pit which normally opens to the exterior.

3. The ciliated pit is lined with a sensory epithelium, with an underlying ganglion innervated from the visceral ganglion by a branch of the posterior pallial nerve.

4. In *Gari*, *Tellina*, and *Solecurtus* the organ opens directly to the siphonal space; in *Macoma* it opens by means of a short duct; in *Scrobicularia* by a long duct; in *Donax*, and also probably in *Tagelus*, the pit does not open to the exterior at all, but into a separate, enclosed cavity.

5. It is suggested that the cruciform muscle and its sense organs form a water-testing apparatus.

6. On the basis of the occurrence of this structure in certain of its members the family Solenidæ is broken into two families: (1) the Solenidæ, without a cruciform muscle; (2) the Solecurtidæ, which possess one.

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IV.—The Developmental Stages of *Euchæta** *norvegica*, Boeck. By

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(With Eight Text-figures.)

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CONTENTS.

Introduction.

Euchæta norvegica is one of the largest known copepods and has a wide range of distribution in northern waters. Sars (1903, p. 38) records it from the deep waters of the fjords along the Norwegian coast and mentions that it occurred in two places in the polar basin crossed by Nansen. With (1915, p. 162) records its presence in North Atlantic waters in various places visited by the Danish Ingolf Expedition. That it is generally distributed throughout the North Atlantic is shown by Bigelow (1924, p. 230). It occurs also in the deep waters of the Clyde sea-area, where at times it is abundant, particularly in Upper Loch Fyne.

The rearing and description of the developmental stages of this copepod were first undertaken by Mitchell (1928), who states (p. 9) that "owing to the impossibility of rearing in the laboratory stages beyond the third nauplius and the absence of some stages in the plankton,

* I have followed With (1915) in using the generic name *Euchæta* in preference to *Paraeuchæta* (Scott, 1909), which has been recently adopted by Wilson (1932) and Rose (1933).

two of the expected naupliar stages have not been dealt with. . . ." Rough drawings of the stages Mitchell identified were handed over to me by Mr Elmhirst, whom I have to thank for the suggestion to complete this piece of work.

All the nauplius stages and the first copepodite have since been reared in the laboratory. Females bearing egg-sacs were placed in separate vessels and the water changed at frequent intervals. In *Euchæta* the ovary is visible through the body-wall owing to its bright blue colour. When the egg-sac is first formed this colour is retained by the eggs, but as development proceeds the blue disappears and the abundant red fat globules give the nauplii a reddish tinge at the time they emerge The egg-sac may become detached from the female, but the eggs will hatch nevertheless. After sufficient time has elapsed for the fertile eggs to hatch the sac is thrown off, and within a few days another batch may appear. The number of eggs in one sac is usually about 50.

The exact time passed between the formation of the egg-sac and the liberation of the nauplii was not determined since the only females under observation were those which already had eggs. It is certainly not less than eight days, which was the maximum time taken by the eggs in any observed case.

As soon as the nauplii were liberated they were removed to separate small beakers and examined frequently at first, 12- or 24-hourly examinations being made later. A large number of nauplii was reared and specimens were fixed at each stage. Every moult was observed, though not on the same specimen throughout.

The diameter of the subspherical egg is 0·4 mm. The nauplius which hatches is 0·55 mm. in length (average of 6 measurements). Within half an hour, sometimes less and occasionally more, this moults into a second nauplius with a length of 0·60 mm. (average of 30). 24 to 26 hours later another moult occurs and the third nauplius emerges, measuring 0·64 mm. (average of 28); this differs scarcely at all, even when seen under the high powers of the dissecting microscope, from the preceding one. Succeeding moults follow one another at approximately 24-hourly intervals. The fourth nauplius measures 0·68 mm.; the fifth 0·73 mm.; and the sixth 0·78 mm. Only a few measurements were available in each case.

Considerable variation in the size of each stage was found, the range in the earlier stages being $\pm$0·01 mm., and in the later stages $\pm$0·02 mm. These measurements indicate how relatively little the animal grows in its nauplius stage and how difficult it is to separate individuals into their correct stage by measurement. This probably accounts for the failure

of Mitchell to identify more than three nauplius stages and his inability to find the missing ones in the plankton. His sketches and measurements in my possession show that he had reared all the six stages, but had classed the second and third as Nauplius II, and the fourth, fifth, and sixth as Nauplius III. This mistake is the more easily made owing to the lack of any definite development in the shape of the body, such as there is in *Calanus* (see text-fig. 2).

Five days elapse before the sixth nauplius moults, and this appears to be the most critical period in the development of *Euchæta*. Up to now very little change has taken place apart from growth (and that very slight), but this moult shows considerable change. The animal increases in length by more than one half; the full number of cephalic appendages is present (the nauplius never had more than three pairs of functional appendages) and two pairs of thoracic appendages are present. It is, in fact, a typical first copepodite, but the sudden change is striking after the slow development of the nauplius. The corresponding change in *Calanus* is accompanied by an increase of only two-fifths of its former length, and the change in shape is less marked owing to the posterior flexion of the body in the later nauplii (*cf.* Lebour, 1916).

One of the first copepodites was kept in the laboratory for 30 days, by which time it had not moulted. This was so long compared with *Calanus* that it was assumed that laboratory conditions were not suitable. At the end of this time it was preserved. Later first copepodites reared from nauplii did not survive so long, and no information has been obtained as to the interval between moults or the time needed for development through the copepodite stages. All the remaining stages were found in the plankton from time to time, as were also the six nauplii, and moults from one stage to the next were observed. A number of measurements of the different stages was made and the average size of each will be found in Table IX.

The types of setæ found in *Euchæta* vary in the different appendages. For convenience the appendages have been described in tabular form, showing segmentation and armature. At the head of each column will be found a letter indicating which type of seta occurs on each segment. These are described below and illustrated in text-fig. 1.

The *bristle* (B), a short, rigid seta.

The *plumose seta* (P), a long, flexible seta, thickly clothed with fine hairs.

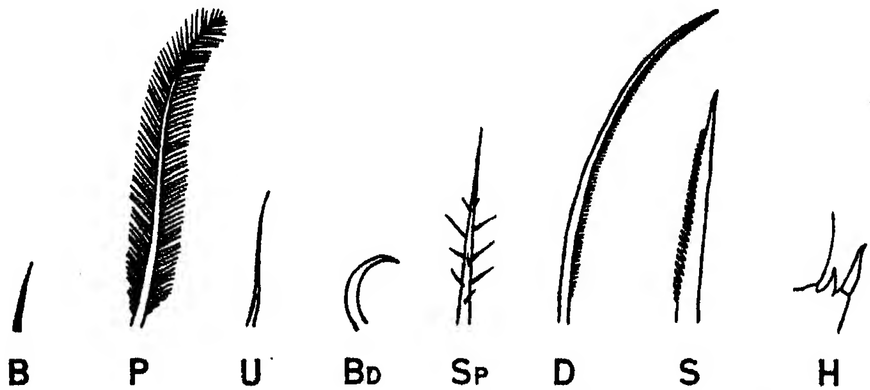
The *unplumed seta* (U), shorter than the preceding type; naked; may become plumose in a later stage.

These three types are the only ones found on the appendages of the nauplii.

The *blade* (BD), a stout, usually curved seta, free from hairs; found on the antenna and mandible.

The *spinous seta* (SP), of varying length, bearing a number of short spines basally; occurs on the maxillule, maxilla, and mandible.

The *denticulate seta* (D), a plain seta, finely serrated along the inner



TEXT-FIG. 1.—The different types of setæ found in *Euchæta norvegica*, somewhat diagrammatic. For description see text.

edge; short setæ of this type occur on the maxillule, longer ones on the maxilla and maxilliped.

The *serrated spine* (S), a thick, rigid seta, deeply serrated along its outer margin; found only on the terminal segment of the exopodite of the 2nd, 3rd, and 4th pairs of thoracic appendages.

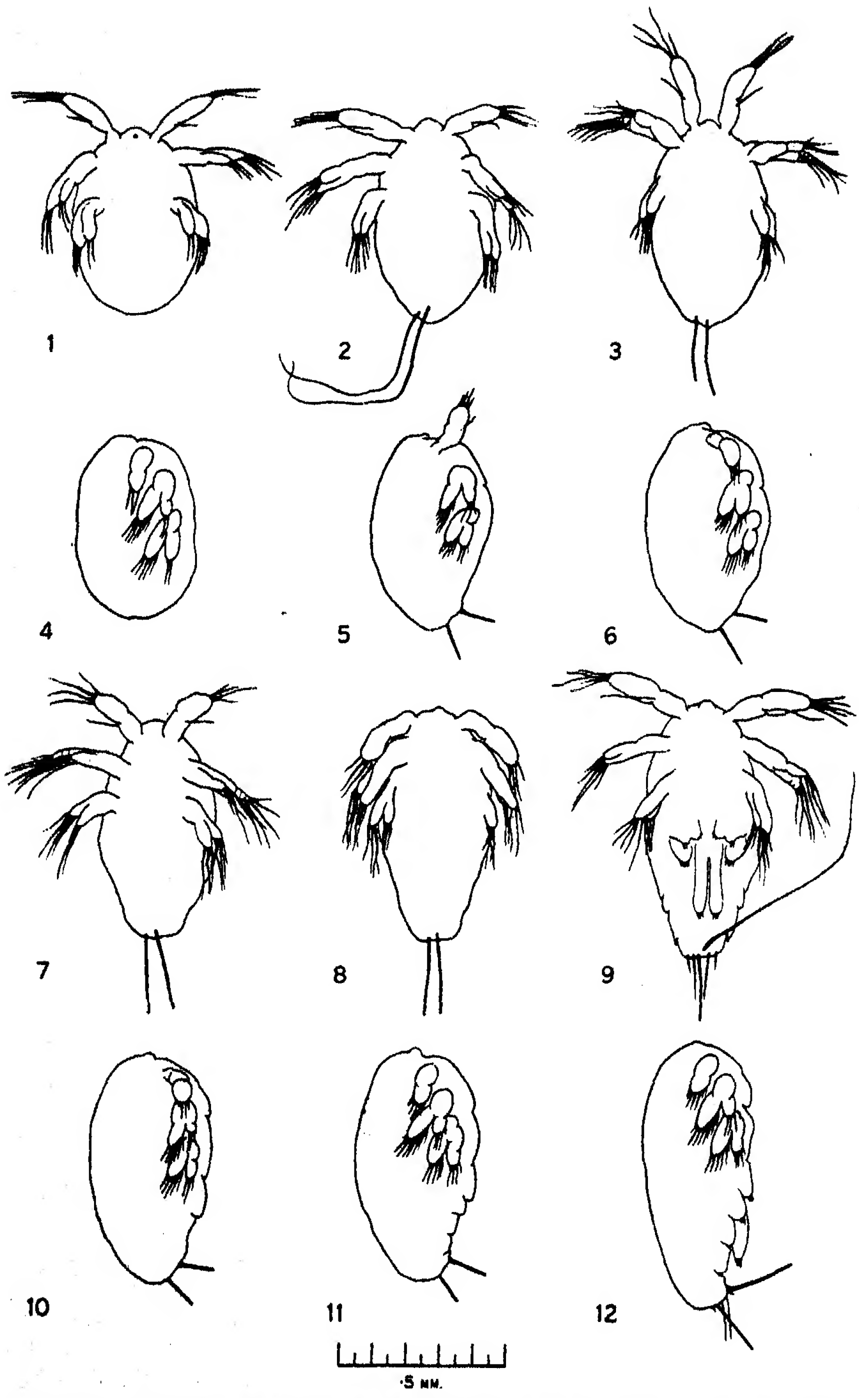
The *hinged spine* (H), a very short, rigid spine occurring only on the outer ramus of the thoracic appendage.

All the drawings except those in text-fig. 1 have been made with the camera lucida, and formalin-preserved material was used throughout. Points of special interest or peculiar features which might have been due to artifacts of fixation were checked by examination of living material.

THE NAUPLII.

The nauplii and their appendages are shown in text-figs. 2, 3, and 4. As already mentioned, relatively little change takes place during the development of the nauplii.

Viewed ventrally the first nauplius is slightly pointed anteriorly and quite rounded posteriorly; there are no hairs on the posterior end. In the succeeding stages the body assumes a more elongate form, becomes ovoid by the third stage and pyriform in the sixth owing to elongation of the posterior half.



TEXT-FIG. 2.—The six nauplii of *Euchæta norvegica*. Figs. 1–3 and 7–9 in ventral view; figs. 4–6 and 10–12 the same in lateral view.

One pair of posterior hairs, as long as or a little longer than the body in each case, appears in the second nauplius and persists to the sixth, in which two pairs of short ones appear. None of these hairs is plumose.

A slight indication of the rostrum can first be seen in the second nauplius when viewed laterally. Not until the sixth stage are the fourth, fifth, and sixth pairs of appendages sufficiently developed to be removed from the body by dissection. Even at this stage from their inflexibility they can scarcely be functional.

The upper lip is practically non-existent (*cf.* Oberg, 1906, and Gurney, 1931) and it appears that the mouth is imperforate, though it has not been possible to discover this with certainty. These points will be discussed later.

A small, pigmented eye-spot is present in all stages, but disappears on preservation. Its position is shown in the first nauplius (text-fig. 2, fig. 1).

Appendages of the Nauplii.

The *Antennule* (text-fig. 3, A1) has three segments in each stage, the proximal segment being unarmed throughout.

The *Antenna* (text-fig. 3, A2) has a coxopodite, basipodite, unsegmented endopodite and 5-segmented exopodite throughout. The coxopodite, in contrast to *Calanus*, is unarmed in every stage.

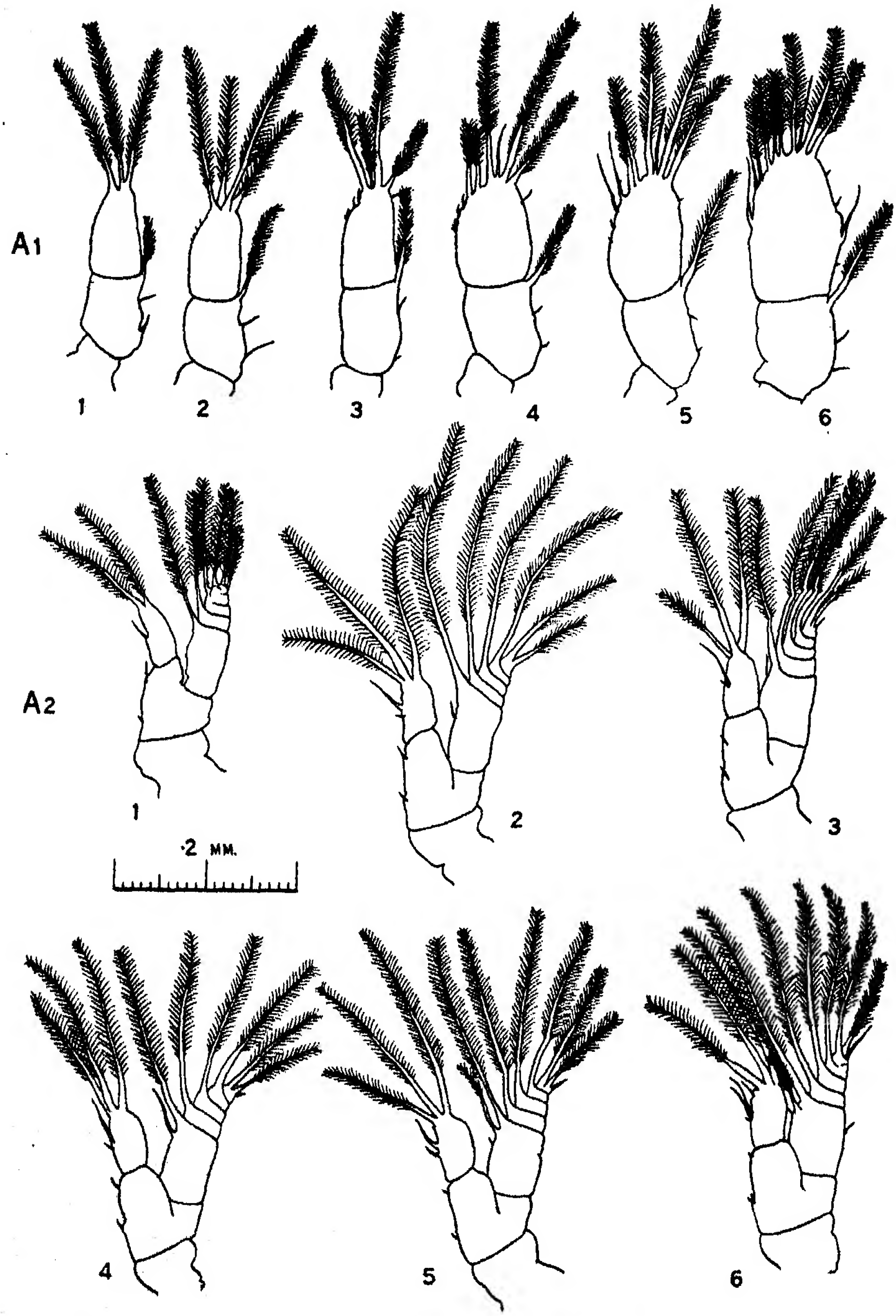
The *Mandible* (text-fig. 4, figs. 1–3) has a coxopodite, basipodite, unsegmented endopodite and 4-segmented exopodite throughout; as in the antenna the coxopodite lacks armature in every case.

Unsegmented maxillules, maxillæ, and maxillipeds are present in the sixth nauplius (text-fig. 2, figs. 9 and 12; text-fig. 4, figs. 4 and 5). Indications of these can be seen in the lateral views of the fourth and fifth nauplii (text-fig. 2, figs. 10 and 11).

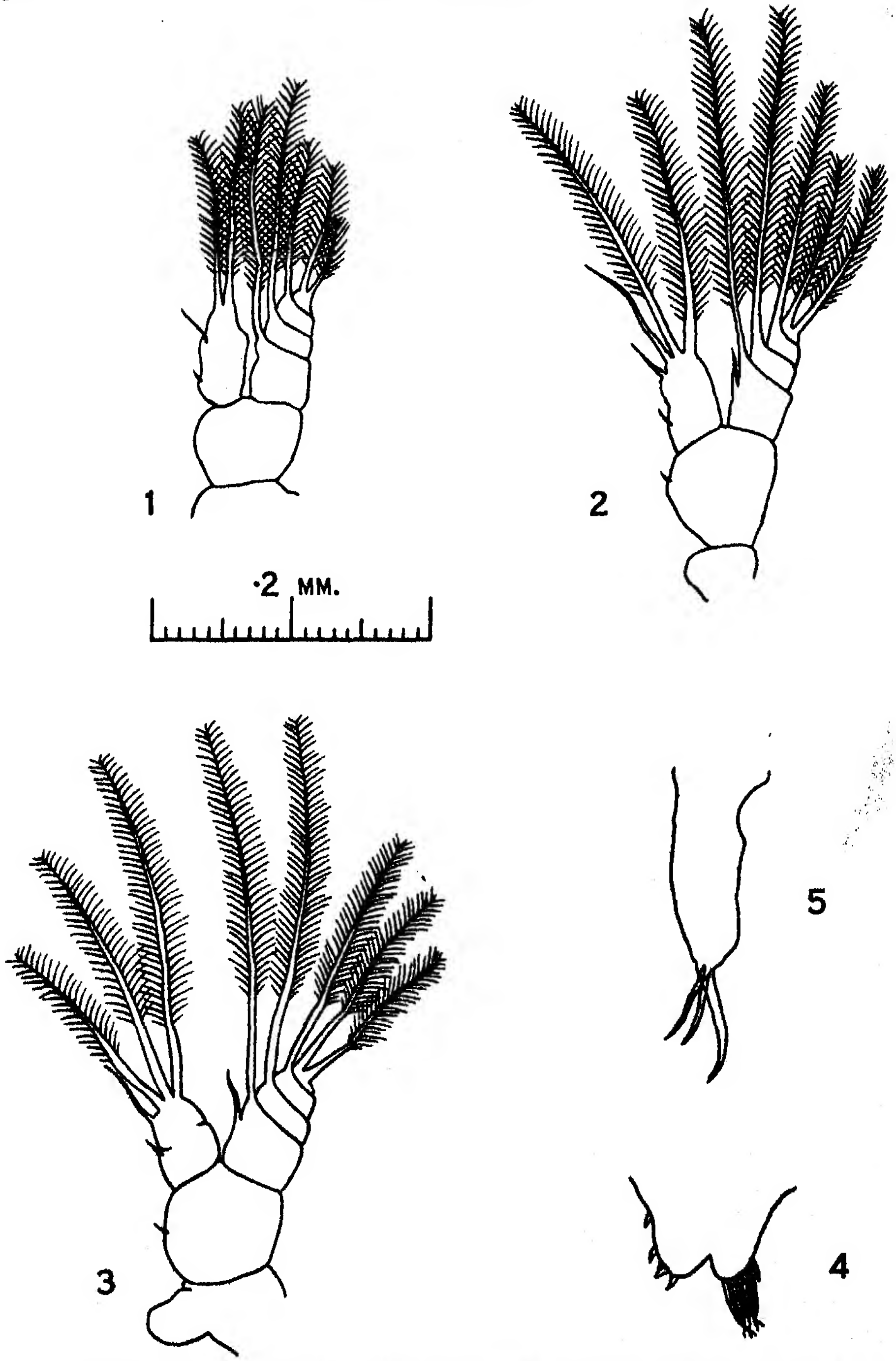
Very small spines are found occasionally but have not been recorded in the table because they have appeared only in the antennule and then inconsistently. Three appear in the antennule of the second nauplius, three in the third, four in the fourth, and none in later stages. A number of dissections revealed that these numbers are not constant.

The gnathobase first appears as a slight lateral protuberance on the mandibular coxopodite of the fourth nauplius; in the fifth and sixth stages it becomes more pronounced. This is illustrated in text-fig. 4, along with other features referred to above.

It will be seen that, since growth is so small from stage to stage and the range in each stage so large as to cause an overlap with that on either side, there is no reliable method of distinguishing any particular stage



TEXT-FIG. 3.—A1 (1–6), the antennules; A2 (1–6), the antennæ of the six nauplii of *Euchæta norvegica.*



TEXT-FIG. 4.—Appendages of the nauplii. Figs. 1, 2, and 3 illustrate the mandibles of the 1st, 2nd, and 6th nauplii respectively; figs. 4 and 5 illustrate the maxillule and maxilliped of the 6th nauplius.

TABLE I.—SEGMENTATION AND ARMATURE OF THE APPENDAGES OF THE NAUPLII.

Antennule.

Stage.	1st Segment.	2nd Segment.		3rd Segment.		
		P.	B.	P.	U.	B.
I	..	1	2	3	..	..
II	..	1	2	4	2	..
III	..	1	2	4	2	1
IV	..	1	2	5	3	1
V	..	1	2	5	5	1
VI	..	1	2	7	4	3

Antenna.

Stage.	Coxo-podite.	Basi-podite	Endopodite.			Exopodite Segments Number 1.			2.	3.	4.	5.	
		B.	P.	U.	B.	P.	U.	B.	P.	P.	P.	P.	U.
I	..	2	2	1	..	1	..	..	1	1	1	2	..
II	..	2	3	1	1	1	1	..	1	1	1	2	..
III and IV	..	2	3	1	1	1	1	..	1	1	1	2	1
V	..	2	3	1	2	2	..	1	1	1	1	2	1
VI	..	3	3	2	2	2	..	2	1	1	1	2	1

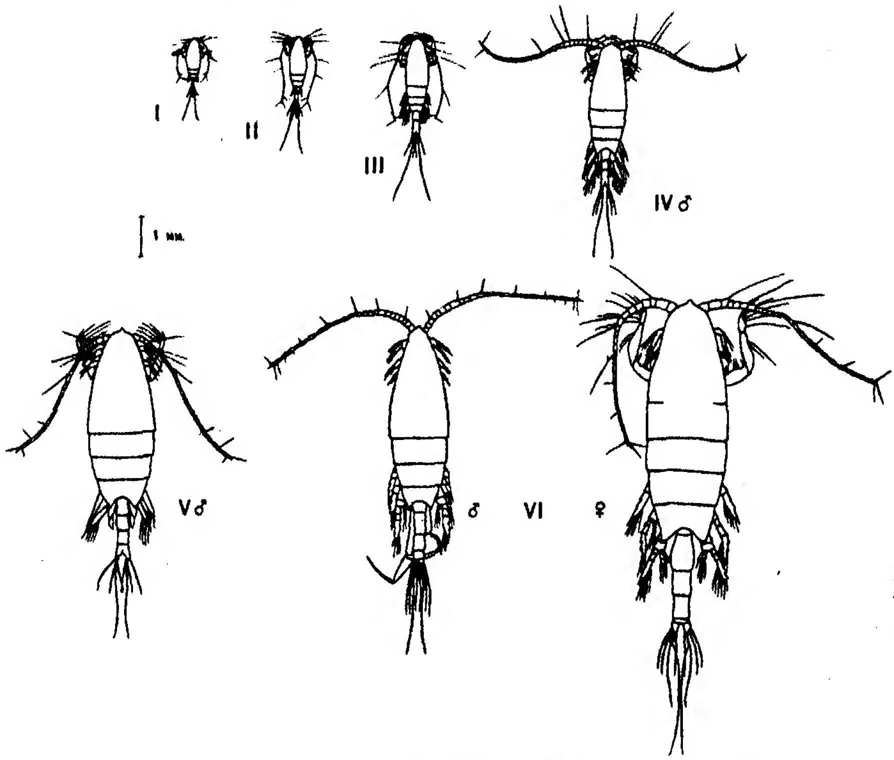
Mandible.

Stage.	Coxo-podite.	Basi-podite.	Endopodite.			Exopodite Segments Number 1.		2.	3.	4.
		B.	P.	U.	B.	P.	U.	P.	P.	P.
I	..	..	2	1	1	1	..	1	1	2
II	..	1	2	2	1	1	1	1	1	2
III, IV, V, and VI	..	1	3	1	1	1	1	1	1	2

at a glance, except for the first and sixth nauplii (which have none and three pairs of terminal hairs respectively). Examination of the antennule is the only sure guide in the identification of any of the remaining stages since this is the only appendage showing definitive changes from one stage to the next.

Copepodite Stages.

There are six copepodite stages, the last being the adult. The sexes are separable from the fourth copepodite onwards, making nine distinct forms; all of these were found in the plankton from time to time. As



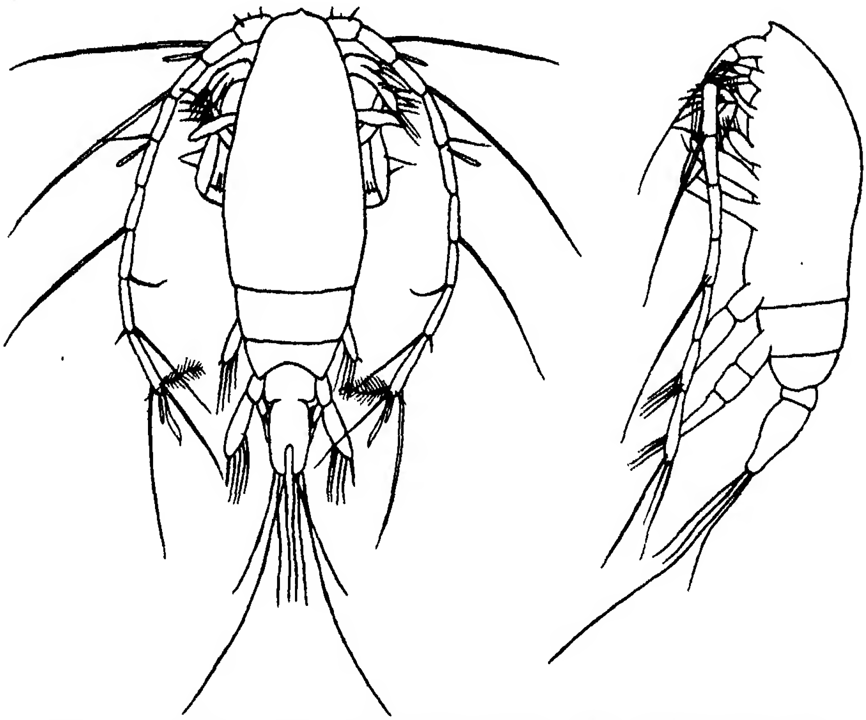
Text-fig. 5.—The copepodite stages of *Euchæta norvegica* in dorsal view, showing the relative size. The females of Stages IV and V have been omitted as they are approximately the same size as the corresponding males. The characteristic appearance of the living copepod is shown in IV ♂.

already mentioned, only the first was reared in the laboratory, but subsequent moults from one stage to the next up to Stage IV were observed. The time-intervals between moults were not discovered owing to the difficulty of keeping the animals alive for sufficient time under laboratory conditions.

The adults (Stage VI, ♂ and ♀) have been fully described and illustrated by Sars (1903). Later they were re-examined by With (1915) and partial descriptions of the younger stages (except Stage I) added.

For this paper complete dissections of all stages have been made, and descriptions of the body and appendages are given throughout in tabular form.

The definitive points by which any stage can be identified without dissection are given in Table IX and illustrated by outline drawings in text-figs. 5 and 6. Each appendage is then treated separately, its segmentation and armature being compared throughout the nine different copepodite forms in a series of tables (II–VIII).



TEXT-FIG. 6.—The first copepodite of *Euchæta norvegica* viewed dorsally and laterally.

The Antennule.—In the first copepodite this appendage has only 9 clearly defined segments, of which the 2nd, 3rd, 6th, 8th, and last bear long hairs; the 2nd, 5th, and terminal segments bear æsthetascs (the name given by Giesbrecht (Calman, 1909, p. 76) to this type of sensory seta); and fine bristles are distributed throughout its length.

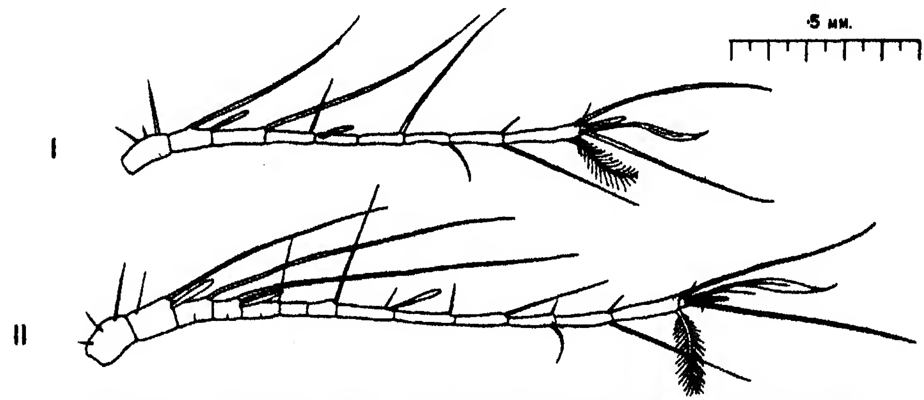
In the second copepodite 14 segments are clearly distinguishable, including the small terminal segment. Segments 3, 4, and 5 show signs of division, making a possible 17. (With (p. 162) records 25 segments in his material—many of them fused.) Segments 2, 3, 4, 13, and 14 have long hairs; 2, 4, 8, and 14 bear æsthetascs (With's material apparently lacked these entirely).

In the third copepodite 22 segments were found (With found 25), of which 2, 5, 6, 21, and 22 bear long hairs; 3, 6, 11, 15, and 22 having

æsthetascs. (With describes these on four segments only, the numbers of which do not correspond with mine as he assumes the full number to be present and indicates which are still fused.)

In the remaining copepodites 24 segments were found (22 in the adult male) and the armature is fairly consistent throughout. Long hairs were present on segments 3, 7, 8, 13, 23, and 24; æsthetascs on segments 5, 8, 13, 18, and 24 in Stage IV, with an extra one on segment 11 in Stages V and VI, and many more in the adult male. Fine bristles are present on nearly every segment throughout, and are much more abundant proximally in the adult male than in the female (see Sars, pls. xxiv and xxvi).

A single plumose seta is present on the penultimate segment of all stages (in the first copepodite the last two segments are not distinct, but



TEXT-FIG. 7.—The antennules of the first and second copepodites showing plumose and spatulate setæ.

the position of this seta is the same) and a flattened spatulate seta appears on the terminal segment in every case (text-fig. 7). In the adult female the plumose seta is strongly developed; in the male it is very much reduced. No reference to these setæ is made by either Sars or With.

The Antenna.—This appendage is almost fully developed in the first copepodite and has been well illustrated by Sars (pl. xxv, A^2). The terminal segment of the endopodite alone shows change from one stage to the next. In the adult male it undergoes a certain amount of reduction, as do the other segments.

The terminal segments of the endopodite and exopodite have their setæ arranged in two groups (see Sars, pl. xxv); this has been indicated in Table II.

The Mandible.—This appendage has been well figured by Sars (pls. xxv and xxvi, M). The gnathobase is well developed and furnished

TABLE II.—SEGMENTATION AND ARMATURE OF ANTENNA.

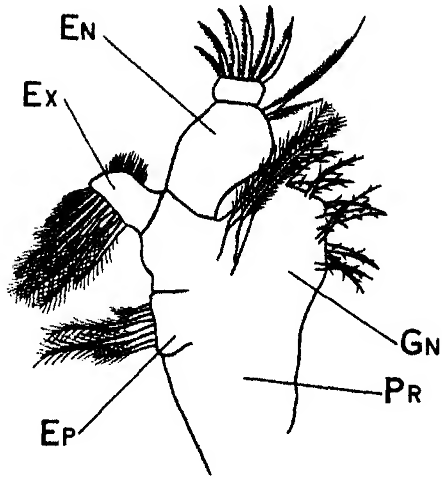
Stage.	Coxo-podite.	Basi-podite.	Endopodite Segments Number			Exopodite Segments Number						
			1.		2.	1.	2.	3.	4.	5.	6.	7.
	Bd.	B.	P.	B.	P.		B.	P.	P.	P.	P.	P.
I and II	1	2	1	1	5+4	..	1	1	1	1	1	1+3
III	1	2	1	1	5+5	..	1	1	1	1	1	1+3
IV, ♂ and ♀	1	2	1	1	6+6	..	1	1	1	1	1	1+3
V, ♂ and ♀	1	2	1	1	6+7	..	1	1	1	1	1	1+3
VI, ♂	Stump	1	..	..	6+7	..	..	1	1	1	1	1+3
VI, ♀	1	2	1	1	6+8	..	1	1	1	1	1	1+3

with strong masticatory processes and spines. The basipodite has a stout curved blade similar to that on the coxopodite of the antenna. The terminal segment of the endopodite, as in the antenna, alone shows change from one stage to the next. In the adult male the masticatory part of the gnathobase is considerably reduced (With, p. 160, pl. vi, fig. 3, *e*); and the setæ are lost from the basipodite and basal segment of the endopodite, the whole appendage being smaller than that of the female. The setæ of the endopodite and exopodite are all plumose.

TABLE III.—SEGMENTATION AND ARMATURE OF THE MANDIBLE.

Stage.	Basipodite.	Endopodite Segments Number		Exopodite Segments Number				
		1.	2.	1.	2.	3.	4.	5.
	Bd.	P.	P.	P.	P.	P.	P.	P.
I	1	1	4	1	1	1	1	2
II	1	1	5	1	1	1	1	2
III	1	1	6	1	1	1	1	2
IV, ♂ and ♀	1	1	7	1	1	1	1	2
V, ♂ and ♀	1	1	8	1	1	1	1	2
VI, ♂	..	..	9	1	1	1	1	2
VI, ♀	1	1	9	1	1	1	1	2

The Maxillule (text-fig. 8).—This appendage (equivalent to the maxilla of Sars) consists of a protopodite, not clearly divisible into coxopodite and basipodite, bearing a large masticatory lobe, two smaller lobes, and an epipodite. The endopodite and exopodite are reduced and not clearly segmented. On the endopodite the setæ are of the short denticulate form.



TEXT-FIG. 8.—Semi-diagrammatic drawing of the maxillule in *Euchæta* (Stage II, copepodite).

TABLE IV.—SEGMENTATION AND ARMATURE OF THE MAXILLULE.

Stage.	Protopodite.			Endopodite.	Exopodite.
	Masticatory Lobe.	Small Lobes.	Epipodite.		
	Sp.	P.	P.	D.	P.
I	9	2	2	8	7
II	9	2	4	8	7
III	10	2	6	10	8
IV, ♂	9	2	9	9	9
IV, ♀	12	2	9	11	9
V, ♂	12	2	9	12	10
V, ♀	13	2	9	13	10
VI, ♂	..	..	5	10	11
VI, ♀	14	2	9	13	11

The denticulate setæ on the endopodite in the adult male are greatly reduced in strength.

The Maxilla.—The segmentation and armature of this appendage (equivalent to the 1st maxilliped of Sars) are constant throughout, as illustrated in Sars' excellent drawing (pl. xxv, mp^1). The maxilla of the adult male, also shown by him, is very greatly reduced. There are four distinct segments, the first and fourth each with two endites, the second and third with one each. The setæ on the first three segments are

all spinous, those on the terminal segment are of two kinds, spinous and denticulate.

TABLE V.—SEGMENTATION AND ARMATURE OF THE MAXILLA.

Stage.	1st Segment. 1.	1st Segment. 2.	2nd Segment.	3rd Segment.	4th Segment. 1.		4th Segment. 2.	
	Sp.	Sp.	Sp.	Sp.	Sp.	D.	Sp.	D.
All stages except VI, ♂	3	3	3	3	1	2	2	4
VI, ♂	greatly reduced—about 12 terminal bristles and a few stumps elsewhere. (See Sars, pl. xxvi, *mp*[1].)							

The Maxilliped.—In this appendage (equivalent to the 2nd maxilliped of Sars) seven segments are distinguishable only from the fourth copepodite onwards. The setæ of the proximal segment are all spinous and are arranged in four groups, the first of which is missing in the first three copepodites. In the adult male this appendage is greatly reduced in size (Sars, pl. xxvi, *mp*[2]), but its armature is only slightly reduced.

TABLE VI.—SEGMENTATION AND ARMATURE OF THE MAXILLIPED.

Stage.	Segments Number														
	1.	2.			3.		4.		5.		6.			7.	
	Sp.	Sp.	B.	D.	PD.	U.	PD.	U.	PD.	U.	PD.	U.	B.	PD.	B.
I	0+1+2+2	1	..	1	5 denticulate setæ.										
II	0+2+2+2	1	..	1+1	1 (D)		1 (D)		4 denticulate setæ.						
III	0+2+3+3	1	1	1+2	1 (D)		1 (D)		6 denticulate setæ.						
IV, ♂ and ♀	1+2+3+3	1	1	1+3	2	1	1	..	1	..	1	1	1	1	..
V, ♂	1+2+3+3	1	1	1+2	2	1	1	..	1	..	1	1	1	3	1
V, ♀	1+2+3+3	1	1	1+2	2	1	2	..	1	1	1	1	1	3	1
VI, ♂	1+0+1+1	1	1	1+2	2	1	2	1	1	1	1	1	1	3	1
VI, ♀	1+2+3+3	1	1	1+2	2	1	2	1	1	1	1	1	1	3	1

Some of the setæ on this appendage are a combination of the plumose and denticulate types, being more denticulate towards the base and more plumose terminally. These have been called plumo-denticulate and are indicated in the table by PD.

The Swimming Feet, 1–4.—Attention has been drawn by Sars (1903, p. 37) and With (1915, p. 159) to the differences between the first pair of thoracic appendages and those which follow. These differences and

the changes that take place in the armature as development proceeds can be seen in the accompanying table (VII). The first copepodite has only 2 pairs of thoracic appendages; the second has 3 pairs; the third and fourth have 4 pairs, which number is retained throughout by the females (unlike *Calanus*, which develops a fifth in both sexes). For illustrations, see Sars, pls. xxv and xxvi.

* TABLE VII.—SEGMENTATION AND ARMATURE OF 1ST SWIMMING FOOT.

Stage.	Coxo-podite.	Basi-podite.	Inner Ramus Unsegmented.	Outer Ramus.					
				1st Seg.		2nd Seg.		3rd Seg.	
		P.	P.	P.	H.	P.	H.	P.	H.
I	..	..	5					5	2
II	..	..	5					6	2
III and IV, ♂ and ♀	..	1	5					6	2
V, ♂ and ♀	..	1	5			1	2	4	1
VI, ♂	..	1	5	..	1	1	1	4	1
VI, ♀	..	1	5			1	2	4	1

2ND SWIMMING FOOT.

Stage.	Coxo-podite.	Basi-podite.	Inner Ramus Unsegmented.	Outer Ramus.						
				1st Seg.		2nd Seg.		3rd Seg.		
	P.		P.	P.	H.	P.	H.	P.	S.	H.
I	..	..	5					3	1	3
II	1	..	5					4	1	3
III and IV, ♂ and ♀	1	..	6			1	1	5	1	3
V, ♂ and ♀; VI, ♂ and ♀	1	..	6	1	1	1	1	4	1	3

* NOTE.—The incomplete separation into columns in this table indicates that the outer rami of the 1st and 2nd pairs of swimming feet and both rami of the 3rd and 4th pairs are not fully segmented except in the later stages.

3RD SWIMMING FOOT.

Stage.	Coxo-podite.	Basi-podite.	Inner Ramus.			Outer Ramus.						
			1st Seg.	2nd Seg.	3rd Seg.	1st Seg.		2nd Seg.		3rd Seg.		
	P.		P.	P.	P.	P.	H.	P.	H.	P.	S.	H.
II	..	..			6					3	1	3
III	1	..			6			..	1	4	1	3
IV, ♂ and ♀	1	..		1	6			1	1	5	1	3
V, ♂ and ♀ } VI, ♂ and ♀ }	1	..	1	1	5	1	1	1	1	4	1	3

4TH SWIMMING FOOT.

Stage.	Coxo-podite.	Basi-podite.	Inner Ramus.			Outer Ramus.						
			1st Seg.	2nd Seg.	3rd Seg.	1st Seg.		2nd Seg.		3rd Seg.		
	P.		P.	P.	P.	P.	H.	P.	H.	P.	S.	H.
III	..	..			6					3	1	3
IV, ♂ and ♀	1	..		1	6			..	1	5	1	3
V, ♂ and ♀ } VI, ♂ and ♀ }	Same as 3rd Swimming Foot.											

5th Pair of Swimming Feet.—These are present only in the male and first appear in Stage IV. They are clearly illustrated for Stages IV and V by With (text-fig. 45, *i*, *l*), while those of the adult have been drawn by Sars (pl. xxvi).

DISCUSSION.

The most remarkable point in the development of *Euchæta norvegica*, when compared with *Calanus*, is the relatively small amount of growth between consecutive nauplius stages, and the sudden increase to the first copepodite.

The average lengths of the six nauplii of *Euchæta* and *Calanus* (Lebour, 1916) are compared in the following table, to which has been added the average length of the first copepodite of *Calanus* (based on

the measurements of over 1400 specimens, for which I have to thank Miss S. M. Marshall) and *Euchæta*.

TABLE VIII.

	Nauplii.						Copepodite.
	I.	II.	III.	IV.	V.	VI.	I.
C. finmarchicus .	·21	·27	·42	·48	·51	·60	·83 mm.
E. norvegica .	·55	·60	·64	·68	·73	·78	1·2 ,,

It will be seen that whereas in *Calanus* the sixth nauplius is three times the length of the first, in *Euchæta* the sixth nauplius is only one and two-fifths the length of the first; and whereas in *Calanus* the increase from the last nauplius to the first copepodite is less than two-fifths (38 per cent.) of the length of the nauplius, in *Euchæta* the corresponding increase is over one-half (54 per cent.).

Development in *Euchæta* appears to be restrained during its life as a nauplius, and a sudden jump in size and in the development of the appendages takes place in the first copepodite with a relatively long time-interval before the moult (5 days).

Gibbons (1933) states that the size of the sixth nauplius of *Calanus* is ·81 mm. During the course of two years' work on *Calanus*, in which many hundreds of these nauplii were seen, in no case did any approach the size stated by Gibbons. The total length of the first copepodite, as obtained from Gibbons's figures, is ·88 mm., which is not excessively large, but this is so close to the size of his sixth nauplius as to indicate little or no growth. The average size in the Clyde sea-area lies very close to the figure given above (·60 mm.).

A further point of considerable interest is the absence of a well-developed upper lip in the nauplius. Stained and mounted specimens, moreover, fail to show any signs of the usual tubular gut and, as far as can be ascertained, this is associated with an imperforate mouth. The usual spines at the base of the antenna and mandible are absent also.

Gurney (1933) has shown that the nauplius of *Misophria* does not feed, and it appears that this is also the case with *Euchæta*. But, whereas the later nauplius stages of *Misophria* are suppressed and it becomes a first copepodite within about a day, there is no such suppression in *Euchæta*, and at least 9 days pass before the first copepodite appears, which would seem to be surprisingly long for it to live without feeding. It can be seen, however, that there is still a large quantity of what appears

to be yolk even in the sixth nauplius, and since actual growth through the nauplius stages is small the yolk supply must be sufficient. Unlike other Calanoids (Gurney, 1931), and possibly associated with this non-feeding habit, is the absence of terminal æsthetascs on the antennules of the nauplii.

TABLE IX.—SHOWING THE DEFINITIVE POINTS BY WHICH ANY COPEPODITE STAGE OF EUCHÆTA CAN BE IDENTIFIED WITHOUT DISSECTION.

Stage.	No. of Free Thoracic Segments.	No. of Pairs of Swimming Feet.	No. of Segments in Urosome.	Length,	
				Excluding Urosome, mm.	Including Urosome, mm.
I	2	2	2	0·9	1·2
II	3	3	2	1·3	1·7
III	3	4	2	1·8	2·3
IV, ♂	3	5	3	2·8	3·7
IV, ♀	3	4	3	2·9	3·9
V, ♂	3	5	4	4·2	5·4
V, ♀	3	4	4	4·3	5·6
VI, ♂	3	5	5	4·4	6·0
VI, ♀	3	4	5	6·1	8·1

The sizes given in this table are based on measurements of material preserved in formalin, which may cause a slight swelling in copepods.

SUMMARY.

The six nauplii and first copepodite of *Euchæta norvegica* have been reared in the laboratory.

The nauplii and their appendages are described in tabular form, and illustrated. The antennule provides the definitive characters of each nauplius.

The appendages of the copepodite stages are dealt with separately and described in a series of tables.

The growth and development of *Euchæta* and *Calanus* are compared. It appears that *Euchæta* passes through its nauplius stages without feeding, being dependent on its large supply of yolk.

A table shows the definitive points by which any copepodite stage of *Euchæta* may be identified without dissection.

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(*Issued separately March* 15, 1934.)

V.—The Weight and Chemical Composition of *Euchæta norvegica*, Boeck. By **A. P. Orr**, M.A., B.Sc., A.I.C., Chemist, Marine Station, Millport. *Communicated by* Professor J. H. Ashworth, F.R.S.

(MS. received October 17, 1933. Read November 6, 1933.)

Euchæta norvegica has been found to be an important constituent of the food of the American pollack (Willey, 1921), and Bigelow (1926) expresses the opinion that it may form an important part of the food of mackerel and herring in the Gulf of Maine. In Loch Fyne in the Clyde sea-area, where *Euchæta* occurs in abundance at certain times of the year, it has never been found in the stomachs of herring (Scott, 1907). This is surprising for, as Scott remarks, *Euchæta* is "rich in oily matter, and apparently is of as much value as *Calanus* for herring food." Macdonald (1927), however, has found that adult *Meganyctiphanes norvegica* feed on *Euchæta*, so, indirectly at least, it contributes to the food of the herring.

The material used for the analyses was taken from catches made by Dr. A. G. Nicholls in Loch Fyne in October and November 1931. No attempt was made to record fluctuations in composition throughout the year. The *Euchæta* were brought to the laboratory alive in jars of sea-water and separated into adult males and females and Stage V males and females before analysis. In addition, some analyses were made of the ovigerous females by themselves. This is to some extent a risky proceeding, for it is not always possible to tell if a so-called non-ovigerous female is one in which the egg-sac has become detached. Comparatively slight disturbance is often sufficient to cause the egg-sac to be dropped. *Euchæta* younger than the fifth copepodite were not analysed owing to scarcity of material. A description of the stages analysed is given by Dr. A. G. Nicholls in the preceding paper. I am indebted to him for the separation of the stages and sexes and the size determinations.

Size and Weight.—Size measurements were made from the tip of the rostrum to the tip of the "small nodiform projection" (Sars, 1903) on the last segment of the cephalothorax.

Dry weight was determined by transferring about 20 individuals after measurement to a Gooch crucible. These were then washed rapidly several times with distilled water to remove the adherent sea-

water, transferred to a weighed coverslip and dried to constant weight at 110° C.

The average size of the adult male *Euchæta* was 4·5 mm. and the average weight of 100 individuals was 138 mg. The range of the results (Table I) suggests that larger numbers would be required for accurate sampling. Adult males were relatively scarce, and this, together with the fact that although slightly larger than Stage V males they were generally but not always lighter than these, suggests that little or no increase of weight takes place after the Stage V males moult to adult males and that thereafter they lose weight and die.

Adult females, on the other hand, were relatively numerous and both large and heavy. The ovigerous females averaged 5·9 mm. in length and weighed 444 mg. per 100 individuals; non-ovigerous females averaged 5·6 mm., which is slightly less than that of the ovigerous females, and weighed only 323 mg. per 100 individuals. The greater weight of the ovigerous females is to be attributed only in a slight degree to the somewhat greater size, and chiefly to the presence of eggs.

In the immediately pre-adult stage, Stage V, there is very little difference between male and female *Euchæta* in either size or weight. The average size of the males was 4·0 mm. and the average weight of 100 individuals 160 mg.; the average size of the females was 4·2 mm. and the average weight of 100 individuals 138 mg. There is thus an increase in size from this stage to adult with female *Euchæta* of about 1·4 mm., while with the males the increase is only 0·5 mm. The increase in weight with development into females is large (about 200 mg. per 100 individuals), while, as has been mentioned, with males it is zero or there is even a slight loss of weight. The decrease in weight, in spite of an increase in length with males, is accounted for by the change in shape of the male *Euchæta*. Sars (1903) showed that the feeding appendages of adult male *Euchæta* are greatly reduced, and With (1915) says that the maxillulæ are useless for mastication. This, in conjunction with the weight-loss, supports the suggestion that after moulting takes place the male *Euchæta* does not feed and there is a gradual loss of weight followed by death.

Ash.—Ash was determined by igniting a weighed sample of washed and dried *Euchæta* to a white ash at red heat with the Bunsen burner. A slight loss by volatilisation may have taken place, but is not likely to have been sufficiently great to affect the percentage appreciably.

Determinations were made only on non-ovigerous females and male Stage V *Euchæta*. Others were not present in sufficient numbers. The ash of the females was 4·4 per cent., and that of the male Stage V was

3·6 per cent. This is approximately the same value as has been obtained by Brandt and Raben (1919–22) with *Calanus* (3·6 per cent.). No analyses of *Euchæta* seem to have been made by other workers, and it is not included in the analyses of mixed plankton catches made by Brandt (1898) or Brandt and Raben (1919–22).

Chitin.—Chitin determinations were made on adult male and female *Euchæta* and on mixed Stage V *Euchæta*. After washing, drying, and weighing, the samples were treated for a short time with dilute hydrochloric acid, and then for a considerable time with 15 per cent. caustic soda at 100° C. When clean, the residue was collected on a sintered glass Gooch crucible, washed successively with distilled water, alcohol, and ether, dried at 110° C., and weighed.

The chitin content of adult male *Euchæta* was 5 per cent., of non-ovigerous adult female *Euchæta* 4 per cent., and of mixed Stage V *Euchæta* 3·1 per cent. The object of the chitin determinations was to find what fraction of the organic material in *Euchæta* could be definitely classed as indigestible. Very few animals are able to digest chitin, and there is no record of fish being able to do so.

Fat and Protein.—Fat determinations were made by a modification of Stoddard and Drury's saponification method (1929). A washed, dried, and weighed sample of *Euchæta* on a coverslip was transferred to a basin and covered with the alcohol-ether mixture and the coverslip carefully comminuted. The resulting glass powder served very well for grinding up the resistant tissues of the *Euchæta*. The remainder of the analysis was carried out as described by Stoddard and Drury with the exception that a fat-free filter-paper was used for filtration and phenolphthalein was used as indicator in the titration (see Stewart, Gaddie, and Dunlop, 1931). The factor used for conversion of titration value to fat is that for triolein used by Brandt and Raben (1919–22) for analysis of mixed plankton catches.

Protein was estimated by transferring a sample of washed, dried, and weighed *Euchæta* to a hard glass tube, combusting with sulphuric acid in the presence of a trace of copper and estimating the ammonia formed by the Folin and Farmer's micro-aeration method (Plimmer, 1920).

The fat content of adult male *Euchæta* was about 23 per cent. of its dry weight, and that of non-ovigerous adult females 21 per cent. The ovigerous females were, however, much fatter (36 per cent.). Stage V male *Euchæta* contained 30 per cent. of fat and the Stage V female *Euchæta* 21 per cent. It might have been expected that the adult male *Euchæta* would have shown a greater loss in fat than the analyses indicate.

There were no appreciable differences in the percentage of protein

present in the different sexes or stages, and the average value was 36 per cent.

The values for fat and protein differ considerably from those hitherto recorded for the marine plankton. Brandt (1928), Brandt and Raben (1919–22), and Wimpenny (1929) all give results which are very much lower than those recorded in this paper. These authors, however, dealt with mixed plankton catches, and the organisms present were invariably much smaller than *Euchæta*. They also find considerable fluctuations in the fat content of plankton, which may depend either on the nature of the catch dealt with or the time of year. The results in the present paper confirm Scott's opinion (1907) that *Euchæta* is a rich food for fish, but the problem of its rejection by the herring of Loch Fyne is left unsolved.

TABLE I.

Date.	Sex.	No. taken for Analysis.	Average Size in mm.	Weight of 100 in mg.	Fat. %	Protein. %	Chitin. %	Ash. %
31/10/32	♂	17	4·5	129	..	41	..	..
	♂	11	4·4	135	26	..	..	..
21/11/32	♂	20	4·5	148	..	34	..	..
	♂	19	4·4	134	21	..	..	..
	♂	27	..	144	..	..	5·0	..
31/10/32	♀ ov.*	10	5·9	436	36	..	..	..
21/11/32	♀ ov.	15	5·9	463	..	31	..	..
	♀ ov.	15	5·9	437	..	..	..	..
31/10/32	♀	20	5·7	314	..	44	..	..
	♀	20	5·7	327	24	..	..	..
	♀	20	5·5	296	..	..	..	..
21/11/32	♀	19	5·7	341	..	33	..	..
	♀	17	5·6	328	..	38	..	..
	♀	19	5·6	310	..	..	..	..
	♀	20	5·6	330	18	..	..	..
	♀	50	..	318	..	..	4·0	..
	♀	50	..	340	..	..	..	4·4
21/11/32	V ♂	18	4·0	177	..	34	..	..
	V ♂	20	4·0	163	..	..	..	..
	V ♂	20	4·0	162	..	35	..	..
	V ♂	20	4·0	165	30	..	..	..
	V ♂	95	..	134	..	..	..	3·6
31/10/32	V ♀	20	4·1	130	..	35	..	..
	V ♀	20	4·2	130	..	..	..	..
21/11/32	V ♀	20	4·2	162	..	38	..	..
	V ♀	20	4·2	140	19	..	..	..
	V ♀	20	4·1	143	..	35	..	..
	V ♀	20	4·2	152	23	..	..	..
21/11/32	V mixed	100	..	163	..	..	3·1	..

* ov. = ovigerous.

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VI.—Studies on the Reproductive System in the Guinea-Pig: Observations on the Ovaries, with special reference to the Corpus Luteum. By Thomas Nicol, M.B., Ch.B., F.R.C.S.E.,

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THE object of the present paper is to put upon record for the guinea-pig data which I have collected regarding (1) the relation between the number of young in a litter and the number of corpora lutea of pregnancy in the ovaries, (2) the distribution of corpora lutea between the two ovaries in two successive ovulations, and (3) the utilisation of the uterine horns in successive pregnancies. The data were obtained in the course of other researches and are arranged in tabular form (Tables I and II). The records from which they have been collected refer to 40 female guinea-pigs killed post partum, of which 16 were pregnant and 24 had not been reimpregnated.* The size of the previous litter is known for 38 of these females; both ovaries were serially sectioned at 10 microns in the 40 animals, but in 4 the records of only one ovary were preserved.

The ovaries were serially examined, and a chart of each prepared in which were entered the number of young corpora lutea, the number of old corpora lutea of the previous pregnancy, and the number of yellow bodies (still older corpora lutea). The old corpora lutea of the previous pregnancy, as is known, are prominent structures in the ovaries after parturition; thereafter they gradually disappear or become "yellow bodies," but may still be recognisable about 27 days post partum (Loeb, 1911; Nicol, 1933).

Size of Litter.

The commonest size of litter in this strain of animals was found to be two, as shown from the following details abstracted from Tables I and II.

Details from 38 females:

6	females	littered	1
21	,,	,,	2
8	,,	,,	3
3	,,	,,	4

* It is to be noted that the animals observed belonged to a strain of animals bred in the laboratory. Great care was taken to avoid in-breeding. The animal house is commodious, well ventilated, and kept at a uniform summer temperature throughout the winter months.

Comparing the number of the previous litter with the number of young embryos present in the 16 pregnant females (Table I), it may be interesting to note that in only 6 does the number of young embryos correspond with the number of the previous litter in the same female. This is in agreement with the findings of Ibsen (1928) for the guinea-pig, who states that very few females produced succeeding litters containing the same number of individuals.

Number of Embryos.

All the embryos shown in Table I were normal, and no degenerating remains of embryos were found. The number of very young embryos was ascertained by the examination of serial sections. In the animals killed 36–82 hours post partum, the ovaries, tubes, and proximal parts of the uterine horns were serially sectioned at 7 or 10 microns; in the animals killed 106 hours to 12 days post partum, the ovaries, tubes, and entire uterine horns were sectioned; in the remainder the embryonic swellings were counted before being sectioned.

From Table I it can be seen that

4	females	had	each	1 embryo
5	,,	,,	,,	2 embryos
5	,,	,,	,,	3 ,,
1	female	,,		4 ,,
1	,,	,,		5 ,,

Two or three embryos was therefore the commonest number found in one female, and the largest number of embryos in one uterine horn was 5.

Number of Corpora Lutea.

It will be seen that

(*a*) Out of 13 pregnant females in which both ovaries were examined, in 5 the number of young corpora lutea and young embryos correspond, whereas in 8 the number of young corpora lutea is greater than the number of young embryos (Table I).

(*b*) Out of 35 females in which both ovaries were examined and the previous litter was known, in 23 the number of old corpora lutea of the previous pregnancy corresponds to the number of the previous litter,* whereas in 12 (marked × in Table I

* In the cases in which the old corpora lutea of the previous pregnancy have disappeared from both ovaries, the number of small "yellow bodies" has been considered as representing the former.

TABLE I.—RECORDS OF CORPORA LUTEA IN THE OVARIES OF GUINEA-PIGS PREGNANT AGAIN AFTER PARTURITION.

Index Number of Animal.	Previous Litter.	Time Post Partum when killed.	Number of Young Embryos. Uterine Horn.		Left Ovary.			Right Ovary.		
			Left.	Right.	Young Corpora Lutea.	Old Corpora Lutea of the Previous Pregnancy.	Small Yellow Bodies.	Young Corpora Lutea.	Old Corpora Lutea of the Previous Pregnancy.	Small Yellow Bodies.
59 ×	3	36 hrs.	1	1	1	4 of which 1 is much smaller.	4	2	2 of which 1 is very small.	0
46	3	58 hrs.	1	0	1	2	0	..	..	..
34	2	82 hrs.	3	0	4	2	0	1	0	0
38	2	82 hrs.	3	0	3	0	0	0	2	0
57	4	106 hrs.	1	0	4	2	0	..	..	..
48 ×	2	6 days 10 hrs.	2	0	2	5	0	2	0	2
158 ×	3	9½ days	1	1	1	4 very small. Mean diam. 0·72 mm.	0	1	5 very small. Mean diam. 0·7 mm.	0
195	3	10½ days	1	2	1	2 very small. Mean diam. 0·66 mm.	0	..	..	..
226	2	10¾ days	2	2	4	0	2	4	0	0
183	2	11¾ days	2	1	3 of which 1 is slightly older.	0	1	2 of which 1 is slightly older.	0	1
81	2	12¼ days	5	0	5	0	0	2	2	0
164	2	13 days 6 hrs.	0	1	0	2 of which 1 is slightly older.	0	1	0	0
197 ×	1	14½ days	0	1	0	0	0	2	3 very small.	0
161	2	19 days	1	1	2	1	0	2	1	0
184 ×	2	20½ days	0	2	0	3 of which 2 are smaller.	0	2	1	0
90	3	25½ days	1	2	1	3	0	2	0	0

In the animals marked with a cross (×) the number of old corpora lutea of the previous pregnancy is greater than the number of the corresponding litter.

and Table II) the number of old corpora lutea of the previous pregnancy is greater than the number of the corresponding litter.

In relation to the latter observation I have not observed any examples of new corpora lutea being formed during pregnancy, although a hæmorrhage may occur into a young corpus luteum about the time of what would have been a "heat" period, nor have I observed any tendency to disappearance of a young corpus luteum during pregnancy. Corpora lutea of the same ovulation, young or old, showed identical appearances and seldom varied in size. Luteinisation of follicles was rarely seen.* Moreover, the boxes which contained the male and female were carefully examined every morning for any remains that might indicate that some of the young had been eaten, and though instances of this might occur and leave no evidence, this could not account for all the twelve examples in which the number of old corpora lutea of the previous pregnancy exceeded the number of the related litter.

Those observations indicate, as would be expected,† that if several young corpora lutea are formed at the immediate post partum ovulation and the animal becomes pregnant, all of these young corpora lutea become corpora lutea of pregnancy, and persist and apparently function throughout pregnancy until after parturition, whether or not all the ova were fertilised or some ova died in utero and were absorbed.

If this be so, then the ovum production rate calculated from the corpora lutea of the previous pregnancy and the young corpora lutea of the succeeding pregnancy together is approximately 3 per animal. The guinea-pig, therefore, in the matter of number of follicles ruptured at each heat period, would seem to be intermediate between the cow, which produces one, and the rabbit, which produces many.

The largest number of young corpora lutea in a single ovary was 5; while the largest number in both ovaries of the same female was 8. Moreover, differences in the number of young corpora lutea between individual ovaries in the same female are seen to be very common, and for the rabbit Hammond and Marshall (1925) believe that probably this is dependent to some extent on the relative amount of nutritive substance necessary for follicular growth in the blood supply of each.

Only in 5 out of 36 females do the numbers of new and old corpora lutea correspond in the same female. This can be understood, however,

* The number of corpora lutea was therefore considered to correspond with the number of eggs shed (compare Hammond, 1921).

† Compare Tables II and III (Hammond, 1914) for rabbit and pig; Table XXV (Hammond and Marshall, 1925) for rabbit; Robinson (1918) for ferret.

as the number of ova shed seems to depend on the level of the anterior pituitary substance in the blood (Zondek and Aschheim, 1927; Smith and Engle, 1927).

Prenatal Mortality.

Robinson (1921) pointed out that a considerable amount of prenatal death is a regular phenomenon in some groups of mammals and probably in all groups. From Tables I and II of non-inbred animals it appears that

Table II.—Records of Corpora Lutea in the Ovaries of Guinea-Pigs *not* Reimpregnated after Parturition.

Index Number of Animal.	Previous Litter.	Time Post Partum when killed.	Left Ovary.			Right Ovary.		
			Young Corpora Lutea.	Old Corpora Lutea of the Previous Pregnancy.	Small Yellow Bodies.	Young Corpora Lutea.	Old Corpora Lutea of the Previous Pregnancy.	Small Yellow Bodies.
189 ×	2	30 hours	0	0	0	0	3	0
192	3	32 hours	3	2	1	4	1	0
196	2	33½ hours	1	2	0	4	0	0
6	..	40 hours	1	2	1	3	2	4
225 ×	1	58 hours	1	1	1	3	2	0
73 ×	2	84 hours	0	2	6	0	2	8
7	..	96 hours	3	2	2	..	..	..
199	2	106 hours	0	1	0	0	1	1
33 ×	2	106 hours	1	1	0	2	2	0
35	2	106 hours	3	2	0	3	0	0
39	2	106 hours	0	2	0	2	0	0
43 ×	2	5 days 6 hours	1	0	1	1	4	0
71 ×	1	5½ days	0	1	0	0	3	0
219	2	6 days 10 hours	3	1	0	2	1	0
188	4	6 days 10 hours	0	2	0	0	2	0
223	1	9½ days	3	1 very small. Mean diam. 0·66 mm.	0	2	0	0
185	3	9 days 4 hours	1	1	2	3	2	0
194	2	12 days 9 hours	4	1	0	1	1	0
190	2	12 days 9 hours	2	0	0	1	2	0
218	4	14½ days	5	0	3	3	0	1
123	3	14½ days	1	1	0	2	2	0
124	2	16½ days	0	0	1	0	2	0
216	1	19 days	4	0	0	0	1	0
191 ×	1	24½ days	2	3	0	2	2	0

In the animals marked with a cross (×) the number of old corpora lutea of the previous pregnancy is greater than the number of the corresponding litter.

in the guinea-pig the prenatal mortality is 29·5 per cent. (calculated from total of previous litters and old corpora lutea of the previous pregnancy).

In regard to whether the prenatal mortality was due to degeneration of ova in the segmentation stage, to later fœtal atrophy, or to lack of fertilisation of the ova shed, it has been noted that no degenerating remains of segmenting eggs or of embryos were found in the present series.* Moreover, if fœtal atrophy was taking place during pregnancy, the ratio between young corpora lutea and normal embryos should have increased as pregnancy proceeded, but from the figures in Table I the ratio is much the same at 6 days and under of pregnancy as it is at 13 days and over.

	Number of Embryos.	Number of Young Corpora Lutea.
6 days and under . .	10	15
13 days and over . .	9	12

It would therefore appear from the present data that lack of fertilisation of the ova shed is the chief cause of the prenatal mortality. Fœtal atrophy, however, does occur in the guinea-pig (Meyer, 1917; Nicol, 1933), but in relation to the number of uteri examined in this laboratory it is relatively uncommon, as compared with what seems to occur in other mammals, such as the rabbit or the ferret. Robinson (1921), from tables by Stockard and Papanicolaou (1918), states that it appears that in the guinea-pig the prenatal death-rate of normal non-inbred lines is 13·30 per cent., but he considers this figure too low. The above prenatal death-rate in the guinea-pig of 29·5 per cent. would bring this rodent approximately into line with the tame rabbit (32·3 per cent. (Hammond, 1921)), the pig (32·6 per cent. (Hammond, 1921)), and the ferret (35 per cent. (Robinson, 1921)).

Distribution of Embryos between the Two Horns of the Uterus in relation to Distribution of the Young Corpora Lutea between the Two Ovaries.

This may be more clearly shown by arranging the animals of Table I, in which both ovaries were examined, in the following groups (Table III).

It can be seen that when embryos are confined to a single uterine horn young corpora lutea may be found only in the ovary of that side, and may correspond in number to the number of embryos (Table III, Group 1), or be greater than the number of embryos (Table III, Group 2), or be found in both ovaries and be greater than the number of embryos

* In Dr Maclaren's laboratory notes of his very large collection of guinea-pig stages, only 3 recognisable examples of degeneration in the tubal stage are noted.

present (Table III, Group 3). Where embryos are present in both uterine horns young corpora lutea are found in both ovaries, and may be equal in number to the number of embryos (Table III, Group 4), or greater than the number of embryos (Table III, Group 5). In no case is the number of embryos in any uterine horn in excess of the number of young corpora lutea in the ovary of that side. There is therefore no tendency for the embryos to be distributed throughout both uterine horns

TABLE III.—SHOWING DISTRIBUTION OF EMBRYOS BETWEEN THE TWO UTERINE HORNS IN RELATION TO DISTRIBUTION OF YOUNG CORPORA LUTEA BETWEEN THE TWO OVARIES.

Group.	Index Number of Animal.	Number of Embryos.		Number of Young Corpora Lutea.		
		Left Uterine Horn.	Right Uterine Horn.	Left Ovary.	Right Ovary.	
1	164	0	1	0	1	No migration.
	184	0	2	0	2	
	38	3	0	3	0	
2	197	0	1	0	2	No migration.
3	48	2	0	2	2	No migration.
	34	3	0	4	1	
	81	5	0	5	2	
4	158	1	1	1	1	No migration.
	90	1	2	1	2	
5	59	1	1	1	2	No migration.
	161	1	1	2	2	
	183	2	1	3	2	
	226	2	2	4	4	

when derived from one ovary. They seem to be confined to the uterine horn of the side on which ovulation occurred (Groups 1, 2, and 4).

The possibility, however, of migration of the ovum from one horn to the other has to be considered, and migration may be "external" or "internal." This question was dealt with by Allen (1932) in his survey of recent research. In the rat and the mouse there is a closed ovarial sack which prevents e x t e r n a l o r a b d o m i n a l m i g r a t i o n of the ovum. In the guinea-pig it is also excluded because of the relation of the ovary to the ovarian bursa; this varies with the stages of the cycle, but at

œstrus the bursa is well closed over the ovary, so that the condition becomes in principle the same as that of the closed capsule of the rat and mouse.

But the possibility of "internal" migration remains. In the pig it appears that ova may pass across the common corpus uteri from one horn to the other. This "internal" migration is anatomically impossible in the rat, mouse, and rabbit because of the arrangement of the cervices, but in the guinea-pig the anatomical relations do not exclude it. The present series of animals, however, give no support for the possibility of such a migration.

Comparison between Two Successive Ovulations in 36 Females, in each of which both Ovaries were Serially Examined.

(Calculated from the number and distribution of young corpora lutea and corpora lutea of the previous pregnancy—Tables I and II.)

It will be seen that

14	females	ovulated	from	both ovaries twice.
7	,,	,,	,,	left ovary then from both.
4	,,	,,	,,	both ovaries then ovulation missed.
3	,,	,,	,,	right ovary then from both.
2	,,	,,	,,	left ovary then from right ovary.
2	,,	,,	,,	right ovary then from left ovary.
2	,,	,,	,,	right ovary then ovulation missed.
1	female	,,	,,	right ovary twice.
1	female	,,	,,	both ovaries then from right ovary.
36	females.			

Therefore although there is considerable variation, ovulation occurs most commonly in both ovaries, and there is no evidence for alternate ovarian action. This is in agreement with the findings of Hammond (1927) for the cow, and Hammond and Marshall (1925) for the rabbit.

The percentage of female guinea-pigs that ovulate from both ovaries is really higher than appears from the above comparison of two successive ovulation periods—*e.g.* (*a*) in one ovulation period out of 36 females 24 ovulated from both ovaries (calculated from number of young corpora lutea—Tables I and II) = 66·6 per cent.; (*b*) in one ovulation period out of 36 females 19 ovulated from both ovaries (calculated from number of old corpora lutea of the previous pregnancy—Tables I and II) = 52·77 per cent. Average number of females which ovulated from both ovaries (calculated from the above two ovulation periods) = 59·7 per cent.

Comparison of Uterine Horns used in Successive Pregnancies.

Migration of ova and alternating action of the ovaries being excluded, it may be assumed for the present series of animals that, when the number of the previous litter was known and old corpora lutea corresponding to this litter were found only in one ovary, the embryos were developed in the uterine horn of that side. Out of the 16 pregnant females shown in Table I there are 10 examples in which there is a clear indication, on this assumption, of the uterine horn utilised in the previous pregnancy. Since for each of these 10 pregnant females the distribution of the embryos between the two uterine horns is known also for the succeeding pregnancy, conclusions may be drawn as to the uterine cornua used in the two successive pregnancies—Table IV.

Table IV.—Showing Comparison of Uterine Horns used in Two Successive Pregnancies.

Index Number of Animal.	Previous Pregnancy.				Present Pregnancy.		Result.
	Number of Young in Litter.	Distribution of Old Corpora Lutea of the Pregnancy corresponding to this Litter.		Uterine Horns Used.	Distribution of Embryos.		
		Left Ovary.	Right Ovary.		Left Horn.	Right Horn.	
34	2	2	0	Left	3	0	Left horn used twice.
48	2	5	0	Left	2	0	Left horn used twice.
197	1	0	3	Right	0	1	Right horn used twice.
164	2	2	0	Left	0	1	Left horn used then right horn used.
38	2	0	2	Right	3	0	Right horn used then left horn used.
81	2	0	2	Right	5	0	Right horn used then left horn used.
*226	2	2	0	Left	2	2	Left horn used then both horns used.
90	3	3	0	Left	1	2	Left horn used then both horns used.
*183	2	1	1	Both	2	1	Both horns used twice.
161	2	1	1	Both	1	1	Both horns used twice.

* In these two animals the old corpora lutea of the previous pregnancy have been reduced to small "yellow bodies"—compare Table I.

From the above data it will be seen that

3 females used the same uterine horn twice.
3 females used the other uterine horn in the next pregnancy.
2 females used one uterine horn in the first pregnancy and both uterine horns in the next.
2 females used both uterine horns twice.

It would therefore appear that in a subsequent pregnancy the uterine horn or horns used is a matter of chance, depending probably on the ovary.

Summary of Chief Conclusions.

1. The observations indicate, as would be expected, that if several young corpora lutea are formed at the immediate post partum ovulation and the animal becomes pregnant, all of these young corpora lutea become corpora lutea of pregnancy, and persist and apparently function throughout pregnancy, whether or not all the ova were fertilised.
2. The average ovum production rate per individual animal is approximately 3.
3. In the same female the numbers of new and old corpora lutea seldom correspond.
4. The "prenatal mortality" is 29·5 per cent., and seems to be chiefly due to lack of fertilisation of the ova shed.
5. There is no evidence that in the guinea-pig migration of ova or blastocysts occurs.
6. There is no evidence for alternating action of the ovaries.
7. In a subsequent pregnancy the uterine horn or horns used is a matter of chance.

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VII.—Spermatogenesis in *Drosophila pseudo-obscura* Frolowa. II. The Cytological Basis of Sterility in Hybrid Males of Races A and B.

By **P. Ch. Koller,** D.Sc., Institute of Animal Genetics, University of Edinburgh. *Communicated by* Professor F. A. E. Crew, M.D. (With Thirty-nine Text-figures.)

(MS. received January 6, 1934. Read March 5, 1934.)

Introduction.

Two races or physiological species (A and B) were found in *Drosophila pseudo-obscura* by Lancefield (1922), who described later (1925, 1929) the genetical behaviour of the interracial hybrids. The present writer (1931, 1932, *a*, *b*) has reported further investigations concerning the sterility of the male and the regional reduction of crossing-over in the female of the interracial hybrids. The results obtained suggested that there are genetic fertility factors, located in the sex chromosome complex, which are primarily responsible for the sterility of the F_1 males. A similar conclusion has been reached more recently by Dobzhansky (1933 *b*) from his cytological studies of hybrid males.

The present writer has been conducting during the last few years a genetical investigation of the interracial hybrids in successive generations, in order to determine the actual cause of sterility in these hybrids. The genetical data relating to this study will appear elsewhere; the cytological part alone is presented here. The spermatogenesis of race A was dealt with in a previous paper (Koller and Townson, 1933). The gametogenesis of pure race B males being similar to that of race A, there is no need to discuss it in detail.

Material and Technique.

The original stocks of races A and B were received, some years ago, from Professor Lancefield. Pair-matings between the two races proved to be somewhat disappointing. The average number of fertile matings in the cross A♀ × B♂ is 20 per cent., in the reciprocal cross B♀ × A♂, 3–5 per cent. In the pure races it is 85 and 78 per cent. respectively.

Ganglia from 5-days-old larvæ, testes from pupæ and from newly hatched males, were dissected out in 2 per cent. urea solution and dipped quickly into strong Flemming solution to which 1 per cent. urea was

added, or else they were fixed in Benda's fluid. When Flemming was used the duration of fixation was 1 hour, after which the testes and ganglia were transferred into 1 per cent. chromic acid and left there for 12 hours. When Benda solution was used the time of fixation was 12–24 hours. The stain used was gentian violet or iron hæmatoxylin. The sections were 4–7 μ in thickness.

The drawings were made by the aid of a Zeiss camera lucida, 90 objective, 1·3 oil-immersion, and $\times$ 30 compensating eyepiece.

The measurements of chromosomes were made by the method of Lewitsky and Araratian (1931).

THE TAXONOMICAL POSITION OF *DROSOPHILA OBSCURA* FALLEN AND *DROSOPHILA PSEUDO-OBSCURA* FROLOWA.

Frolowa and Astaurow (1929) carried out a thorough investigation of *D. obscura* found in Russia. Cytological studies on the flies show 5 pairs of chromosomes. The X has median, the Y-chromosome subterminal, attachment constrictions, producing V- and J-shaped figures respectively. The 2nd, 3rd, and 4th pair of autosomes are V-shaped, the attachment constriction being located at the middle in the 2nd, whilst its locus is submedian in the 3rd and 4th. The 5th pair is the *m*-chromosome, very small and rod-like (*cf.* Frolowa and Astaurow, 1929, figs. 1–2).

Gerschenson (1925) reported *D. obscura* from the Russian Zvenigorod district which showed an abnormal sex-ratio, the average number of males being 4–5 per cent. Frolowa found that the number of chromosomes in this type was 12, and concluded that most probably the 4th pair of autosomes had undergone fragmentation (*cf.* Frolowa, 1929, fig. 3). She found metaphase plates with a similar chromosome arrangement in normal *D. obscura*, which suggests that the fragmentation of the 4th pair of autosomes is not infrequent.

The American *D. obscura*, as classified by Sturtevant (1921) and Duda (1924), shows chromosome complements different from that found in the Russian type. The number is the same, but only the sex chromosomes are similar in the two forms. The 2nd, 3rd, and 4th pairs of autosomes are rod-shaped and of different sizes. Furthermore, Astaurow has demonstrated characteristic morphological differences in the external sexual organs of the American and Russian types, and suggests that the complete absence of copulation in matings between the two is referable to these differences. On these grounds Frolowa and Astaurow suggest that the Russian and American *D. obscura* are two distinct species, and the Russian type must be clearly distinguished from the American, which should be called *D. pseudo-obscura* Frolowa.

The American type has usually been referred to as *D. obscura* (Lancefield, 1922, 1925, 1929; Metz, 1926; Koller, 1931, 1932 *a*, *b*; Koller and Townson, 1933; Crew and Lamy, 1930). Recently, however, in the American literature, the same species is referred to as *D. pseudo-obscura* (Dobzhansky, 1933 *b*; Dobzhansky and Boche, 1933; Schultz, 1933), and so this terminology is accepted.

Comparison of Chromosome Complement of Race A and Race B in *Drosophila pseudo-obscura*.

Three chromosome complements taken from larval ganglia of race A are illustrated in figs. 1, 2, and 3. The X-chromosome is V-shaped with median, and the Y is J-shaped with subterminal attachment constrictions. The approximate ratio of the two limbs is 1 : 6. The length of the X-chromosome is 2·8 μ, that of the Y is 1·75 μ (1·50–0·25 μ). Dobzhansky (1933 *b*) gives figures of the somatic chromosome complement of *D. pseudo-obscura* and, according to him, the length is 2·8–3 for the X, and 1·50 μ for the Y-chromosome. However, he used a different geographical race of type A and a different cytological technique, hence the slight deviation. The autosomes show slight differences in size. The 2nd and 3rd are of approximately the same length, 1·25–1·50 μ. The 4th pair of autosomes is shorter (1·00–1·20 μ).

The somatic chromosome complement of race B is illustrated in figs. 4, 5, and 6. The X-chromosome is longer than in race A, its size being about 2·8–3 μ. The Y-chromosome has a submedian attachment constriction, as contrasted with the subterminal position in race A. The length of the Y is 2·8 μ, the long arm is as long as, or even longer than, the limb of the X-chromosome. This chromosome has a secondary constriction in the long arm, but it is represented more often as a slight bend and is difficult to detect. The distance between the secondary and primary constrictions is equal to that of the short arm of the Y. A secondary constriction was never found in the Y-chromosome of race A. Dobzhansky and Boche (1933) regard the long Y of race B as belonging to the A group.

The autosomes are very similar to those of race A. The 2nd and 3rd are about equal in size, being approximately 1·50–1·75 μ, as is also the arm of the X-chromosome. The 4th pair is shorter, about 1·10–1·20 μ, always less than the short arm of the Y-chromosome, which is 1·20–1·30 μ long. Table I gives the approximate lengths of the chromosomes in the two races.

Another interesting feature of the chromosome complement of race B as compared with that of race A is, that the X-chromosome commonly

has the shape of a very widely opened V, which makes it sometimes difficult to distinguish from the Y-chromosome, especially if the chromosomes are viewed from an angle and are not lying in the equatorial plate.

TABLE I.—THE LENGTH OF CHROMOSOMES IN RACE A AND B OF *DROSOPHILA PSEUDO-OBSCURA*.

	Approximate Length in Micra.	
Chromosome.	Race A.	Race B.
X . . .	2·8	2·8–3
Y . . .	1·75 (1·50 : 25)	2·8–2·9 (1·60 : 1·20–1·30)
2nd . . .	1·25–1·50	1·50–1·75
3rd . . .	,,	,,
4th . . .	1·00–1·20	1·10–1·20
5th . . .	..	..

Somatic complements of hybrids were investigated in the dividing cells of larval ganglia (figs. 7–12). The most striking feature of these complements was the disorderly arrangement of the metaphase plates.* Somatic pairing, *i.e.* the side by side arrangement of the homologous chromosomes, was described by Metz (1916) as a property of the Diptera. This somatic pairing reveals the internal relationship of homologous chromosomes, and was very clearly seen in the pure races. The metaphase plates of the hybrid crosses show chromosomes disarranged to a certain extent, but not so great as was found in race A carrying translocations (figs. 13–15).

The somatic chromosome complement of hybrids derived from the cross A ♀ × B ♂ is illustrated in figs. 7–9. This cross is more fecund and cytologically more interesting than the reciprocal mating. The Y-chromosome in the interracial hybrid is similar to that of the above described type found in race B, showing a submedian attachment constriction. Differences in the length of the autosomes in the hybrid were not found, probably owing partly to the small size of the chromosomes and partly to the bending of chromosomes which causes such variation in length. It is interesting to note that the Y-chromosome was usually located opposite the X, and that the small 5th pair of autosomes was commonly found among the other chromosomes and not in the centre.

The somatic complement of the hybrid cross B ♀ × A ♂ is illustrated in figs. 10–12. The position of chromosomes in the equatorial plate during mitosis is somewhat more disturbed than in the reciprocal cross. The X-chromosome, lying across the metaphase plate in the form of an open V, sometimes divides the plate into two groups. This arrangement is

* Other irregularities during mitosis will not be considered here.


1


2


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4


5


6


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8


9


10


11


12

FIGS. 1, 2.—Chromosomes of male; and 3, female of race A.
FIGS. 4, 5.—Chromosomes of male; and 6, female of race B.
FIGS. 7, 8.—Chromosomes of male; and 9, female hybrids of A♀×B♂.
FIG. 10.—Chromosomes of female; and 11, 12, male hybrids of B♀×A♂.

×4500.

an interesting one, because the tendency of the X-chromosome to take up such a position is characteristic of the sex chromosome in race B, and this tendency becomes obvious in the interracial hybrid where the X-chromosome is of the same origin, *i.e.* of race B. In the reciprocal cross the X-chromosome of race B is obtained from the paternal side; this tendency to open out is obscured.

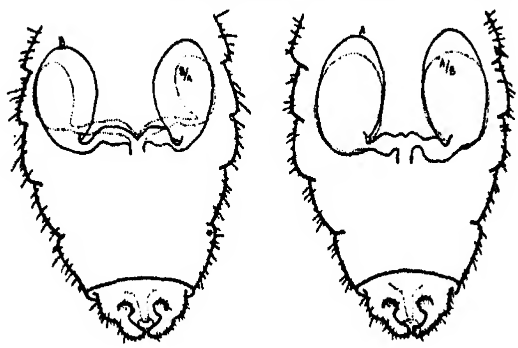
The number of the chromosomes is diploid in the interracial hybrids; only one larva was found showing tetraploid tissue in a section of the ganglia. This larva was from the cross B ♀ × A ♂.

In analysing the chromosome complements of the interracial hybrids it is necessary to point out that the above-described features of the complements exhibit considerable variation, and it is doubtful that the differences in the arrangement at metaphase plate would represent internal differentiation in the two complements respectively.

Spermatogenesis in the Sterile Hybrid Males.

The testis of race A is longer and narrower than that of the pure race B. Males from the cross A ♀ × B ♂ have testes approximately the same as those of the pure race A (fig. 39 and Table II).

(1) *Hybrid Males from the Cross A ♀ × B ♂.*—Spermatogenesis is commonly to be observed at the periphery of the testis of race A, but dividing



A. B.

Fig. 39.—The size and position of testis in pure races and hybrid males.

spermatogonial cells are to be found only in the apex of the testis of the hybrid male.

The formation of spermatogonia is different from that found in the pure races (Koller and Townson, 1933). The mechanism of mitotic division is apparently normal, the daughter chromosomes separating to the opposite poles to form the daughter nuclei. Karyokinesis, however, is not always followed by cytokinesis, and consequently cells with two

nuclei are formed (fig. 16). Thus there are two kinds of spermatogonia, one with the normal diploid, the other with the tetraploid chromosome number.

TABLE II.—THE APPROXIMATE SIZE OF TESTIS IN PURE RACES AND IN THE HYBRIDS.*

Males.	Length.	Width.
A	700–730 μ	320–350 μ
B	680–710 μ	270–300 μ
A ♀ × *B* ♂	610–630 μ	310–340 μ
B ♀ × *A* ♂	260–270 μ	140–160 μ

* Testes of 50 males was measured in each group.

In normal diploid spermatogonia of the interracial hybrid during meiotic division the chromosomes do not pair or associate. In diakinesis, where the association between homologous chromosomes was clearly seen in the pure races A and B, the chromosomes are usually represented as univalents. The number and structure of the chromosomes of the first spermatocytes show beyond all doubt that the association of homologous chromosomes is absent. Fig. 17 illustrates diakinesis; the X- and Y-chromosomes are composed of two chromatids, slightly separated at the terminal segments. The 5th pair of autosomes is missing. Fig. 18 shows one bivalent; the small dot chromosomes are located at the periphery of the nucleus. The position of the univalents at diakinesis is different from that of bivalents seen in the meiotic division of the pure race A. The bivalents showing mutual repulsion are arranged in the peripheral region in normal gametogenesis, but this is not the case in the presence of univalents which are scattered in the whole nucleus.

The univalents do not form an equatorial plate but lie disarranged on the spindle, most probably retaining their previous position in the nucleus. In most of the cases it is rather difficult to decide whether the figures represent diakinesis or early metaphase. Comparison of figs. 19 and 20 with the two previous figures does not show a very great difference in the meiotic stages at prophase, only a more advanced condensation of chromosomes.

At anaphase the segregation of univalents is at random, they pass to that pole which is nearer to them, and form nuclei with varying chromosome numbers. Fig. 21 illustrates anaphase of the first spermatocyte in the interracial hybrid, the X- and Y-chromosomes migrating to the opposite poles. Fig. 22 shows complete disjunction. Fig. 23 illustrates anaphase with separating bivalent. The univalents separate in advance of the bivalents in the meiotic division. The bivalents remain in the metaphase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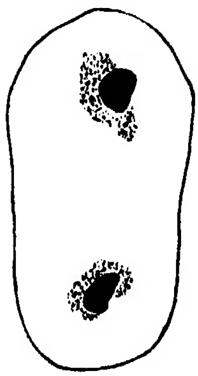
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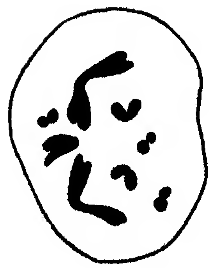
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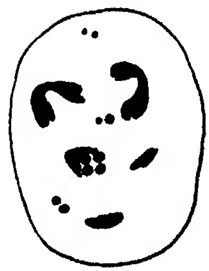
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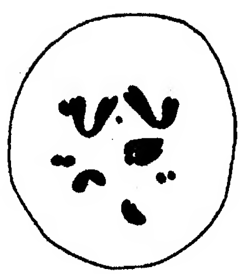
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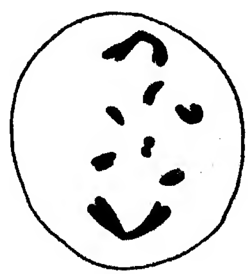
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FIGS. 13, 14, and 15.—Chromosomes of race A carrying translocations.
FIG. 16.—Binucleate spermatogonium.
FIGS. 17 and 18.—Diakinesis.
FIGS. 19 and 20.—Metaphase.
FIG. 21.—Anaphase.

× 4500, except fig. 16, which is × 3300.

plate and separate normally, the segregation being always disjunctional. On the other hand, in several plant hybrids obtained from interspecific crosses, univalents are present, and in these the bivalents always separate first and move towards the poles, the univalents lagging behind as described by Kihara (1931), Catcheside (1932), and more recently Bleier (1933).

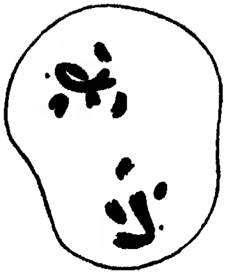
The exact identification of the paired chromosomes which form bivalents at diakinesis and metaphase is very difficult. However, the comparison of bivalents found in several spermatocytes suggests that the 2nd or 3rd longer autosomes are most probably concerned in the formation of bivalents.

Anaphase in the hybrid males lasts longer than it does in the pure races. During this time the chromosomes scatter at the pole and do not fuse together to form daughter nuclei. Meantime the spindle elongates, and thereafter a longitudinal increase in the length of the spermatocyte occurs; it becomes thinner, particularly in the middle (fig. 24). The chromosomes at the pole, after this increase in size, fuse together into a nucleus which usually contains an aneuploid chromosome number. The binucleate spermatocytes undergo further growth in an axial direction and become transformed directly into spermatids without going through a second division.

There is another type of irregularity in the interracial hybrid males. The successive divisions of binucleate spermatogonia usually give rise to similar binucleate cells with a tetraploid chromosome number. The spermatogonia with two nuclei form two separate spindles, parallel to each other. The chromosomes of each nucleus remain distinctly separate (fig. 25). But at late anaphase or telophase fusion of chromosomes occurs. The spindle looses its bipolarity, the daughter chromosomes, although they have already migrated towards the poles, fall apart and scatter toward the centre of the cell. The number of chromosomes is $4n$ (fig. 26). At the central region the chromosomes fuse together and form a large nucleus.

Sometimes the chromosomes of the two nuclei are either advanced so far in their migration towards the pole, or else the bipolarity of spindle is retained so long that the chromosomes can fuse to form two separate daughter nuclei. After completion of cytokinesis, there are thus two spermatogonia, similar to the one from which they have been derived, and containing two nuclei. If this process is repeated it leads to the formation of tetraploid tissue; such was actually found in the testis of several interracial hybrids.

In the tetraploid spermatocytes, as in the diploid, the chromosomes are



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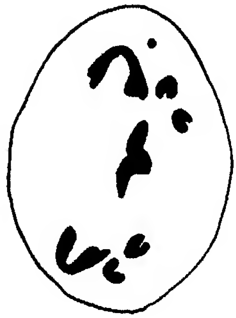

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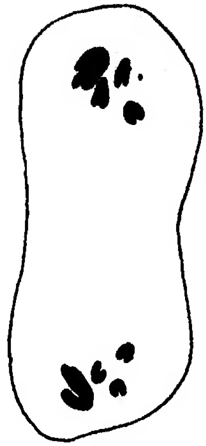

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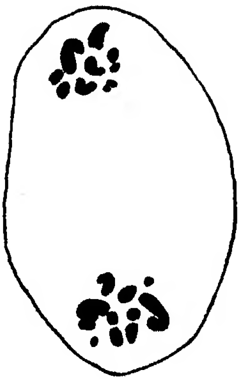

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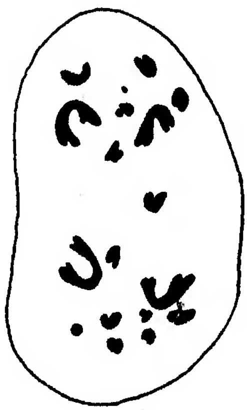

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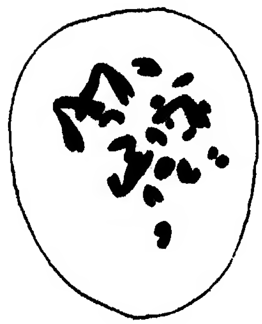

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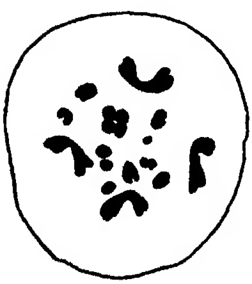

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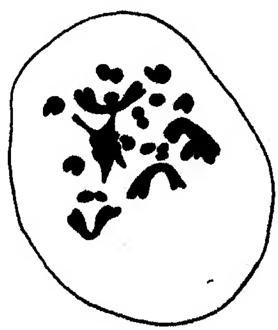

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FIGS. 22 and 23.—Anaphase.
FIGS. 24 and 25.—Late anaphase.
FIG. 26.—Spermatocyte with tetraploid chromosome number.
FIGS. 27–30.—Diakinesis and metaphase in tetraploid spermatocytes.

×4500.

present usually as univalents. Fig. 27 illustrates diakinesis in the tetraploid spermatocyte, only univalents being present. In fig. 28 one bivalent can be seen among the univalents. Fig. 29 shows a spermatocyte with two bivalents. This is a rare phenomenon in the tetraploid cells. Sometimes large bodies were found in the tetraploid spermatocytes which might be taken for "quadrivalents." Figs. 30 and 31 illustrate such multivalent association where these quadrivalents can be seen. Bivalents were not found in association with a quadrivalent in one and the same cell, as was illustrated by Dobzhansky (1933 *b*). It is not improbable that the 2nd or 3rd pair of autosomes which formed the bivalent during meiotic prophase in the diploid spermatocytes are associated to form a quadrivalent in the tetraploid cells with the result that the bivalents are absent in these cells.

Metaphase plates are not formed during this abnormal meiosis. The univalents are scattered in the cytoplasm in the same way as was found in the previous stage. Only the bivalents and quadrivalent are arranged at the centre of the cell. Their segregation is disjunctional for the bivalents, but it can be non-disjunctional for the quadrivalent (figs. 30, 31). Anaphase with lagging bivalents is illustrated in fig. 32. The univalents migrate towards the poles at random; their number is usually different at the two poles.

Telophase of the first spermatocyte is prolonged. The chromosomes are scattered about the pole without fusing together. Cytokinesis is arrested and the cell growth is most pronounced. The giant spermatocytes contain groups of chromosomes at the two poles and represent the $4n$-chromosome number. The number of chromosomes, however, is not necessarily the same at the opposite poles; it may vary as a result of previous non-disjunction.

The chromosomes sometimes divide at the poles and give rise to octoploid spermatids, the second meiotic division being absent. In some spermatocytes it was found that the mitotic division took place after the fusion of the chromosome complement of the two poles. The resulting octoploid cells show a further increase in length, usually bending into crescent-shaped spermatids and gradually degenerating.

(2) *Hybrid Males from the Cross B ♀ × A ♂.*—The testis is very small and few dividing spermatogonia were found. The greater part of the testis is filled with undifferentiated connective tissue. In the adult male the testis is filled with debris of disintegrated cells; in very young pupæ there are few dividing spermatogonia which show clearly abnormal meiotic processes.

The spermatogonia usually contain one nucleus only. At diakinesis

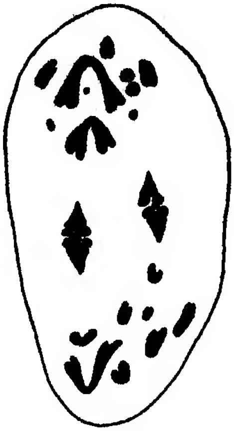
of the first spermatocyte division univalents are present. Figs. 33 and 34 show diakinesis, the chromosome behaviour being similar to that found in the reciprocal cross. Only three cases of meiotic division where a bivalent was present in the complement were found. The rarity of bivalents in this cross compared with the reciprocal matings is a very interesting feature of spermatogenesis in the interracial hybrids derived from the cross of race B ♀ × A ♂.

The chromosomes are scattered about the cell during metaphase, and do not form an equatorial plate. The formation of the spindle is delayed, being formed only at the end of metaphase. The univalents come together in twos, threes, or more. This process is illustrated in fig. 36, which shows the beginning of anaphase. In fig. 37 three groups of chromosomes can be seen. The probable cause of such grouping of anaphase chromosomes is the formation of a multipolar spindle which orientates the univalents in three or even more directions. At metaphase there are usually chromosomes which lag behind the other univalents. Such lagging univalents under the influence of the multipolar spindle are unable to respond with direct movement and migrate towards a definite pole.

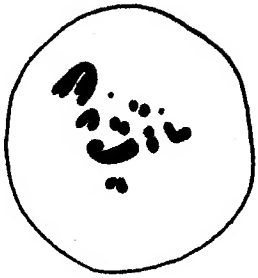
At the end of anaphase the univalents which segregated to the same pole fuse together to form a nucleus. First spermatocytes with two, three, or more nuclei were recognised. They vary in size owing to the difference in chromosome number. Sometimes, however, univalents lag at the centre of the multipolar spindle so long that they are not included into any formed nuclei, and are lost. Apparently one univalent alone is unable to form a separate nucleus. The multinucleate spermatocyte increases in size to resemble a large ovoid cell at metaphase, when the multipolar spindle is formed. Later the increase is in the axial direction (fig. 36). The sex chromosomes usually pass towards opposite poles, and they were never found to remain behind the other univalents, scattering at the centre of the spindle.

The second division is absent. Sometimes the nuclei of the same spermatocyte fuse together. If they are far apart the nuclear content may resolve into chromosomes and move towards the centre of the cell to form a common nucleus with increased chromosome number. Bi- or tri-nucleate spermatocytes, however, are not uncommon. After the fusion of nuclei the first spermatocyte elongates and becomes similar to the cells found in the reciprocal crosses. Crescent-shaped cells with two nuclei can be frequently seen in the testis. The size of the nuclei is different (fig. 38). Although the spermatocyte undergoes further increase in size it does not divide, but soon a process of disintegration ensues and gradually the testis becomes filled with large vacuolated cells.

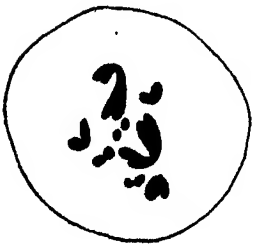
31



32



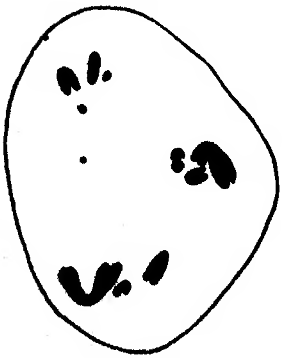
33



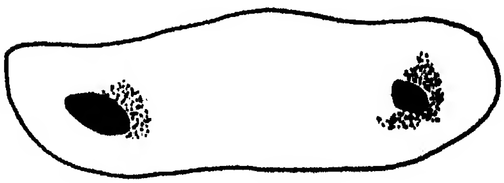
34

35

36



37



38

Fig. 31.—Diakinesis and metaphase in tetraploid spermatocytes.
Fig. 32.—Anaphase.
Figs. 33–35.—Diakinesis.
Figs. 36 and 37.—Anaphase.
Fig. 38.—Elongated spermatocytes with two nuclei of unequal size.
×4500, except fig. 38, which is ×3300.

There are differences in the spermatogenesis of the two hybrids. The hybrids of B ♀ × A ♂ exhibit commonly only two divisions; one is the normal mitotic division to form spermatogonial cells, the second is the first meiotic division. During this division no pairing occurs and frequently a multipolar spindle is formed. No further division occurs. Tetraploid spermatocytes and octoploid spermatids were not found. Owing to the enormous growth of the individual cells after completing the two divisions, the histological structure of the testis is greatly altered.

Discussion.

The processes of meiotic division of the interracial hybrid males are highly abnormal. The most important feature of spermatogenesis is the absence of chromosome association at diakinesis and metaphase in the first spermatocytes. The association of homologous chromosomes at meiotic prophase, although somewhat different in the Diptera from that found in higher plants and animals, can be seen in the pure races (Koller and Townson, 1933). Similar associations were found in *D. melanogaster* by Metz (1926), Guyénot and Naville (1929), and Huettner (1930). In the interracial hybrid males, univalents were present at diakinesis with the exception of one or two pairs of autosomes. Bivalents are formed more frequently in the cross A ♀ × B ♂ than in the reciprocal.

The generally accepted "law of pairing," established from several observations of meiotic division in plants and animals, the general validity of which has been demonstrated by Darlington (1932 *a*), states that homologous chromosomes pair in twos either in diploid or polyploid. The pachytene association is based on the internal homology of the chromosomes, *i.e.* non-homologous chromosomes or segments of chromosomes are *a priori* excluded from pairing, as was demonstrated by Dobzhansky (1932, 1933 *a*), Beadle (1932), Emerson and Beadle (1933). From pairing it can be postulated with certainty that the chromosomes are homologous, but one cannot be sure whether the presence of unassociated chromosomes is due to non-homology or to genotypic control.

If the "law of pairing" is valid in its application in the sense that non-paired chromosomes always must be dissimilar in their internal differentiation, then the presence of chromosomes as univalents in the meiotic division of the hybrid males would suggest that two non-homologous chromosome sets are involved. Hence the sterility of the males would find its explanation in the simple fact that the two chromosome complements are differentiated in their internal constitution to such a degree that they have become dissimilar, and consequently no association

of corresponding chromosomes can occur in the meiotic prophase. However, the following facts prevent such simple explanation:—

(1) The partial fertility of the hybrid females.
(2) Occasional pairing of the 2nd or 3rd autosomes.
(3) Multiplication of chromosome set.
(4) Formation of a quadrivalent in a tetraploid cell.
(5) Different chromosome behaviour in the reciprocal crosses.
(6) Genetic behaviour of the hybrids.

(1) It was found by Lancefield (1929) and by the present writer (1931, 1932 *b*) that the females resulting from interracial crosses are partially fertile when they are back-crossed to either of the pure races. Oogenesis in the hybrid females gives rise to a small number of viable and functional gametes with the haploid chromosome number. The chromosomes of the hybrid are not sorted out in the gametes, chromosomes from both sets being present. Furthermore, genetic experiments have shown that crossing-over takes place in the sex chromosomes and autosomes (data unpublished). These two important facts suggest that (*a*) gametes with haploid chromosome number are viable in spite of the presence of chromosomes derived from different races, and (*b*) normal segregation and crossing-over occur, so that pairing of the two corresponding homologues or homologous segments must have happened previously. If the chromosomes pair at pachytene in the hybrid female, either completely or partially (the latter view is held by the writer), then the unpaired condition of chromosomes during diakinesis and metaphase in the hybrid males cannot be due to dissimilarity in the two chromosome sets. Furthermore, the increased crossing-over at the middle segment of the X's in the hybrid females is a definite proof of complete similarity between these segments in the two races. In Drosophila there is an indirect relationship between crossing-over and length, as has been demonstrated by using different translocations (Dobzhansky, 1932). Failure of pairing and crossing-over in one segment should lead to an increase in the frequency of crossing-over in other segments, for if the shorter chromosomes have a higher relative frequency, so must the reduced pairing segments of the larger chromosomes. The reduction of crossing-over in the distal, and the increase of crossing-over in the middle, segments of the X-chromosomes show that these are homologous segments; thus the non-pairing of chromosomes in the hybrid males is not a consequence of dissimilarity between the two chromosome sets.

(2) Bivalent formation in the abnormal spermatogenesis occurred. It is more frequent in the male derived from the cross A ♀ × B ♂ than

from the cross B ♀ × A ♂, although in both cases bivalents were found in the meiotic complex. The present writer has observed one bivalent, whilst Dobzhansky (1933) has described cases with two. The bivalents were identified in both crosses, and most probably represent the 2nd or 3rd autosome pair with terminal or subterminal attachment constriction. The association of these chromosomes to form bivalents shows that they are internally closely related and are homologous. If this is so, they might be expected to pair in every, or nearly every, meiotic prophase. It was found, however, that in the cross A ♀ × B ♂ about 12 per cent., in B ♀ × A ♂ hybrid only 2 per cent. of the dividing spermatocytes showed bivalents in the complex. This very small percentage suggests that the 2nd or 3rd pair of autosomes, although so highly related in their internal structure as to be able to pair, usually remain unassociated, a phenomenon which must have been brought about by causes other than heterology.

(3) In the hybrid male derived from the cross A ♀ × B ♂ tetraploid spermatocytes were observed. The multiplication of the heterologous chromosomes in a sterile, usually interspecific, hybrid invariably leads to the formation of a new polyploid species with high fertility. The best-known case is that of *Primula kewensis* which is a tetraploid species, containing two sets each of *P. veticillata* and of *P. floribunda* chromosomes (Newton and Pellew, 1929). Complete autosyndesis takes place during meiotic division, and gametes are formed with one *verticillata* and one *floribunda* chromosome set.

If the arrest of association of corresponding chromosomes were due to heterology, duplication of the chromosome complement in the hybrid male ought to have led to pairing in the tetraploid spermatocytes. Tetraploidy was found, but no pairing of chromosomes were seen in the hybrid, except in a few cases where one or two bivalents or one quadrivalent was present. The absence of the pairing in the tetraploid spermatocyte is strong evidence that the cause of sterility cannot be cytological only, because the most effective condition of pairing is restored by duplication of the chromosome sets.

(4) Quadrivalents were seen in two tetraploid spermatocytes. Three other cases were found where the configuration suggested that there are quadrivalents present, but it could not be ascertained critically. The cases illustrated (figs. 30 and 31) show disjunctional and non-disjunctional arrangements. This term is applied, however, only numerically, referring to the possible segregation at anaphase. It has been already mentioned that in the formation of the quadrivalent most probably the 2nd or 3rd autosomal pair participates, *i.e.* the same chromosomes as are associated in the diploid cells and form bivalents. The pairing of the bivalents is

allosyndetic, the associated chromosomes being derived from the different races. In the formation of quadrivalents the association of participating chromosomes may be of two kinds: (*a*) auto- and allo-syndetic, or (*b*) allo-syndetic only. In the latter case the quadrivalents most probably would form a ring. However, it is rather difficult to determine what kind of association takes place in the quadrivalents. If in the diploid cells during meiosis allosyndesis may occur, then it is highly probable that in the tetraploid cells during meiosis autosyndesis can occur as well as the allosyndetic association.

(5) The comparison of the abnormal spermatogenesis in the reciprocal crosses shows very obvious differences. In the hybrid from B ♀ × A ♂ the bivalent formation is less frequent than in the reciprocal cross. Similarly, tetraploid spermatocytes were not observed. The spindle is highly abnormal, usually shows multipolarity, and the formation of polynucleate spermatocytes is very common. The occasional syndiploidy does not lead to the production of a tetraploid cell, although the conditions are favourable. Furthermore, it must be remembered that in this crossing the testes of the hybrid males are very small.

One would infer from such differences that the cytoplasm has an important influence on chromosome behaviour, and that it may be in some degree responsible for sterility in the male. This assumption may be corroborated by other observations derived from usually sterile, but occasionally fertile, hybrids, as is the case in the mule (Cavazza, 1931) and in avian hybrids enumerated by Ghigi (1931), and discussed in detail by Brieger (1930). The different fecundity of the females in the reciprocal crosses and the difference in the sex ratio in successive generations certainly suggest some cytoplasmic influence during gametogenesis in the two kinds of hybrid males.

However, by back-crossing F_1 females of B ♀ × A ♂ to males of race A, a chromosome constitution similar to that of males derived from the cross of A ♀ × B ♂ was obtained, and these males show the same features during spermatogenesis as do males of A ♀ × B ♂ in the F_1 generation. This observation proves that if the cytoplasm has any influence it is not the primary cause of the sterility in the interracial hybrid males.

(6) From the genetical behaviour of hybrid females Lancefield (1929) suggested that "there is incompatibility between certain genes in the X-chromosome of either race with genes in other chromosomes of the other race." The present writer put forward a hypothesis in 1931, based upon observations derived from repeated back-crosses of hybrid females in successive generations, in which it was assumed that the genetic factors which produce sterility in the male are located at the end segments of the

X- and Y-chromosomes and are complementary in their function in the male. These factors were called fertility factors.

That such factors do exist was demonstrated by Stern (1929), who located the fertility complex in the terminal segments of the Y-chromosome of *D. melanogaster*. Hanson and Heys (1933) also arrived at the conclusion that such genes exist. It is most probable, therefore, that in the interracial hybrid the same kind of genetic factors are responsible for the sterility in the male, the complexes being borne on the X- and Y-chromosomes and functioning as complementary factors.

In the light of the recent cytological observation of spermatogenesis in the hybrid it must be pointed out that the action of these factors is not a direct one; probably they produce sterility in the male by interfering with the mechanism of meiosis during spermatogenesis. It is accepted by cytologists that genes are responsible for chromosome behaviour. The genotypic control of chromosome behaviour, either in meiosis or in mitosis, has recently been discussed by Darlington (1932 *b*). Blakeslee (1928) in *Datura* and Beadle (1930) in *Zea mays* reported recessive genes which arrested the pairing of homologous chromosomes and caused high sterility.

Conclusions.

It may be concluded that most probably the ultimate causes of sterility in the hybrid male are genotypic, the genes being complementary in their action, and that the penultimate cause of sterility, the absence of association of corresponding chromosomes during meiotic prophase and metaphase, is brought about by those genetic factors. The occasional pairing of the 2nd or 3rd pair of autosomes strongly suggests that although the chromosome complements of the pure races are slightly differentiated, as can be inferred from the partial "allosyndesis" in the hybrid female, the 2nd or 3rd pair has remained homologous and similar as a whole. In the sterile males, under varying internal conditions, the genotypic constitution sometimes permits and sometimes does not permit the pairing of these homologous chromosomes.

Summary.

(1) The differences in the somatic chromosome complements of race A and B of *Drosophila pseudo-obscura* Frol. are described.

(2) Somatic pairing of corresponding chromosomes was disturbed at mitosis, and no association of chromosomes was found at meiotic prophase; they are represented usually as univalents.

(3) Islands with tetraploid spermatogonia and spermatocytes were

observed. In two cases quadrivalents were present in the tetraploid spermatocyte of a hybrid male derived from the cross of A ♀ × B ♂.

(4) The second meiotic division is absent. Giant spermatids are formed directly after the first spermatocyte in the male offsprings of A ♀ × B ♂. They contain probably $4n$-chromosomes.

(5) Multinucleate spermatogonia and spermatocytes were found in males derived from the cross B ♀ × A ♂. Frequently the nuclei are fused, but this is not followed by further division. The spindle in this male is highly abnormal, usually multipolar. The spermatids are elongated and crescent-shaped.

(6) Sperms were never found in the interracial hybrid males. After the first meiotic division degeneration and disintegration take place in the testicular tissue.

(7) The possible causes of sterility in the interracial hybrid male are discussed. It is suggested that the cause of such sterility is a "genotypically" controlled failure of pairing, and that it is not due to structural differences between homologous chromosomes preventing this pairing. Factors, which may be called fertility factors, are borne on the sex chromosomes, and act in a complementary way in the male. Cytological observations prove that this assumption is highly probable.

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VIII.—The Atomic Weight of the Calcium contained in very Old Potassium-rich Minerals occurring at Portsoy, Banffshire, and at Cape Wrath, Sutherlandshire. By William W. Smith and Thomas Tait. *Communicated by* Professor James Kendall, F.R.S.

(MS. received July 3, 1933. Revised MS. received January 23, 1934. Read July 3, 1933.)

THE radioactivity of potassium was discovered by Campbell and Wood (1907). Since the β-ray activity shown by all the potassium salts investigated was very small, the suspicion naturally arose that this activity was due to a trace of radioactive impurity and not to the potassium itself. All tests for the presence of an emanation gave, however, negative results, and it became necessary to conclude that the observed emission of the β-radiation was indeed a property of the potassium atom. The subsequent investigations of Campbell (1907) and of Hoffman (1924), whose attempts to alter the activity by chemical operations were unsuccessful, supported this conclusion, as did also the work of Biltz and Marcus, who prepared specimens of potassium sulphate from potassium minerals of different geological ages and found that the activity of the preparations per atom of potassium was always the same.

From the rate of emission of β-rays a rough estimate was made of the half-transformation period of potassium. The measurements are difficult on account of the very slight activity exhibited, and the half-value period, $1 \cdot 5 \times 10^{12}$ years, first put forward by Holmes and Lawson (1926) after a general survey of the question, was only tentative. This estimate, based on the assumption that all the atoms of the element are similar in their radioactive behaviour, had to be revised when Aston demonstrated that potassium consists of two isotopes of masses 39 and 41, and subsequent experiments indicated that only the isotope of mass 41 emits β-rays. Hevesy (1927) subjected liquid potassium to a series of ideal distillations; the heavy end-fraction was collected and an atomic weight determination by Hönigschmid yielded a value 0·005 unit higher than that of ordinary potassium. The activity of this heavy end-fraction was determined by Biltz and Ziegert (1928) and found to be about 4 per cent. greater than that of ordinary potassium. It is concluded, therefore, that the isotope of mass 41 is mainly, if not entirely, responsible for the β-radiation of

potassium. Now the isotope of mass 41 forms, according to latest investigation (Baxter and Alter, 1933), only one-fifteenth of ordinary potassium, and thus if this isotope is responsible for all the observed activity it will have a half-value period of 1×10^{11} years.

Recent work by Mühlhoff (1930), and also by Hevesy, Seith, and Pahl (1931), however, has indicated that the above figure is probably too low, and the most favoured current estimate of the half-value period is 1×10^{12} years.

Since the emission of a β-particle raises the nuclear charge by one unit, the potassium isotope of mass 41 should change into a calcium isotope of mass 41. Such an isotope is at present (except for the recent work of Allison; see next paragraph) unknown; only those of masses 40 and 44 have been recognised by the mass-spectrograph. The important point emerges, however, that the existence of this Ca^{41} isotope might be established by an atomic weight determination on the calcium contained in very old potassium-rich minerals, especially if they contain only a small percentage of calcium, for under these conditions it is quite possible that enough of the potassium isotope of mass 41 had changed into the Ca^{41} isotope to raise the resultant atomic weight of the calcium above the normal value of 40·076. If the half-value period of 1×10^{11} years for K^{41} is correct, then since the consolidation of the earth's crust about 0·1 per cent. of potassium has changed into calcium, while if the value of 1×12^{12} years is the true one, this percentage falls to 0·01.

A magneto-optic method discussed by Allison and Goslin (1932) makes possible the detection of Ca^{41} in potassium from minerals of practically any age. Examination for Ca^{41} in samples of sylvine disclosed the presence of a minimum of light intensity intermediate in the scale between the minima due to Ca^{40} and Ca^{44} and appropriate to Ca^{41}. This minimum, presumably due to Ca^{41}, was sought for in fourteen commercial calcium salts, and in only six of them was it observed. Thus the minimum is not due to a third isotope of ordinary calcium. Further, prolonged search failed to reveal the presence of a third isotope of ordinary potassium which might be responsible for the activity of that element. Remarkable results were obtained in the determination of the approximate percentage of Ca^{41}, a sample of sylvine from Stassfurt giving a Ca^{41} percentage of 0·2. All the results obtained by Allison are thus in harmony with the assumption that the transformation product of the K^{41} isotope is a calcium isotope of mass 41, and that the half-value period is low enough to ensure that, if a suitable mineral can be found, it should be possible to prove the existence of Ca^{41}, by showing that the calcium contained in the mineral has a higher atomic weight than ordinary calcium. Further, if

the age of the mineral is known, then the atomic weight difference, especially if this be large, may be utilised to furnish a confirmatory estimate of the half-transformation period of the K^{41} isotope.

Two attempts have been made to discover if these atomic weight differences actually exist, one by A. and O. Frost (1930), and the other by Hönigschmid and Kempter (1931). Of these two only the latter deserves extensive mention, since the atomic weight determinations in the former case were in error to the extent of 0·25 per cent., and this was the order of difference found in the atomic weight values.

Hönigschmid and Kempter used as their starting material calcium oxalate derived from sylvine, performing as well a parallel series of experiments with ordinary calcium, following closely the methods due to Richards and Hönigschmid (1910), which will be given in detail later. After a long series of determinations the value $40{\cdot}085 \pm 0{\cdot}0006$ was put forward as the atomic weight of ordinary calcium. In the case of the calcium oxalate from sylvine, two precipitations as oxalate preceded the usual method of purification, which was shown to be inadequate since the two mean values found, 40·194 and 40·226, were proved to be in error attributable to the presence of strontium. Removal of strontium by the only method apparently successful, namely, by repeated precipitation as oxalate, led to a final value of the atomic weight of 40·091.

This atomic weight difference, although small, is quite definite. The source of the calcium which yielded this result was sylvine, the age of which has been estimated to be approximately 200 million years: a larger atomic weight difference is to be expected by the choice of a much older mineral. Two such minerals have been selected as sources of calcium for the purpose of the present research—pegmatites from East Head, Portsoy, Banffshire, and from Cnoc-an-Tuir (between Rhiconich and Achriesgill), near Cape Wrath, Sutherlandshire (*Geological Survey, Summary of Progress for* 1917, pp. 31 and 33). The pegmatite from Portsoy belongs to a series of pegmatite veins intrusive into rocks of unknown age. In the *Geological Survey Memoir* of the district "Banff, Huntly and Turriff," it is grouped doubtfully with the Newer Granites, which are usually considered to be of Caledonian Age (Post-Silurian). If these two assumptions are valid, the age is then in the neighbourhood of 400 million years (Holmes, 1927, p. 78). The Rhiconich pegmatite is one of a series of pegmatite veins intrusive into the Lewisian gneiss, which is generally considered to belong to early Pre-Cambrian times. This series of pegmatites is definitely older than the Torridonian sandstone of the district, which is thought to be of late Pre-Cambrian Age —about 600 million years (Holmes, *loc. cit.*). It may be much older than

this, but how much it is impossible to estimate with existing data. The value 1000 million years may, however, be taken as a conservative estimate of the age of this pegmatite.

Both of these rocks fulfilled another condition necessary for the purpose of the research, namely, they contained a large percentage of potassium and only a very small percentage of calcium. The analyses given in the *Geological Survey, Summary of Progress for* 1919, pp. 43–4, are as follows:—

	Portsoy Pegmatite.	Rhiconich Pegmatite.
K_2O	8·90	9·35
CaO	0·28	0·27

The results of our own analyses are presented in a later section.

Experimental.

The atomic weight of calcium was determined by evaluation of the ratio $CaCl_2 : 2Ag$, following the method of Richards and Hönigschmid (1910).

Balance and Weighing.

The balance used in the research was a Kuhlmann microanalytical balance with a beam of 70 mm. and a maximum load of 20 grams. Owing to the circumstance that the three knife edges were parallel and lay in the same plane, the sensitivity remained practically constant with changing load, and by following the method recommended by Richards it was possible to standardise the weights with an accuracy of $\pm 0·005$ milligram. The balance was housed in a sheltered room where the temperature was maintained at $18 \pm 0·5°$ C. It was further protected from draughts by being enclosed in a compartment of tinfoil and then in a small cardboard house capable of seating the observer. During the preliminary experiments with the balance it early became evident that careful thermal regulation of the room was a matter of supreme importance, for not only did a variation in temperature produce, inside the balance-case, air currents causing disturbing effects of serious magnitude, but it also resulted in an alteration of the zero-point deflection. The balance was illuminated from a distance of 6 feet by a 60-watt lamp enclosed in a box, the aperture of which was shielded by a "cooling" solution of potassium chromate.

All weighings were made by substitution, and, as the counterpoises were always similar in size and shape to the object to be weighed, the weights required were never large, and consequently changes in the meteorological conditions could be neglected.

In reducing weights in air to weights *in vacuo*, the densities of the various substances had to be taken into consideration. The platinum-covered brass weights had a density of 8·3, and the corrections for 1 gram of substance weighed in dry air at 10° C. and 760 mm. are given in the table below.

Substance.	Density.	Vacuum Correction.
Silver	10·49	−·000032
Calcium chloride . .	2·15	+·000377

The fractional weights were of aluminium of density 2·6, and corresponding corrections were applied at 18° C. and 760 mm.

Substance.	Density.	Vacuum Correction.
Silver	10·49	−·000351
Calcium chloride . .	2·15	+·000097

The wide differences between the densities of brass and calcium chloride, and silver and aluminium, made it necessary to record the barometric pressure when silver and calcium chloride were weighed. Graphs were drawn giving these corrections.

Preparation of Pure Materials.

The most efficient methods of purification may fail to yield a pure product unless extreme care is paid to the exclusion of dust and the various gases sometimes contained in the air of the laboratory. The air of the room was therefore kept as pure as possible, while all operations of transference or evaporation were performed under a large, clean glass plate supported by stout glass rods and placed inside a fume cupboard which had been thoroughly cleaned. When crystallisations had to be performed or solutions evaporated, the heating was conducted electrically, the platinum basins used being placed on pyrex-beakers wound with nichrome ribbon and heated to about 450° C. All vessels containing pure materials were always kept covered and under bell-jars when not in use.

The vessels used in purifying materials were nearly always of quartz or platinum. In only one case, and this a permissible one, was pyrex glass used.

Water.—Large amounts of pure water were required, and for its preparation a 5-litre pyrex-glass flask fitted with a ground-in condenser and ground-in receiver was used. The best laboratory water, of conductivity about $1·5 \times 10^{-6}$ r.o., was distilled with baryta and potassium permanganate to remove carbon dioxide and organic matter. The

distillate was rejected whenever its conductivity rose above 1×10^{-6} r.o. This water was good enough for most purposes, and it was stored in stoppered Jena glass bottles which for many years had only been employed for keeping the best conductivity water. For the final recrystallisations of calcium nitrate and calcium chloride, and for the final nephelometric tests, the water was distilled immediately before use through a quartz condenser.

Nitric Acid.—A.R. nitric acid was distilled with small quantities of barium nitrate and silver nitrate to remove possible traces of sulphate and chloride. The head and tail fractions were rejected and the middle fraction was redistilled. This process was twice repeated, the head and tail fractions being each time rejected. A pyrex-glass flask with ground-in condenser was employed for the distillations.

Hydrochloric Acid.—Constant-boiling A.R. hydrochloric acid, containing a few crystals of potassium permanganate to remove bromine and iodine, was slowly distilled from a pyrex flask fitted with a ground-in condenser. The middle fraction was twice redistilled, once through pyrex and once through quartz, and each time the head and tail fractions were rejected.

Ammonium Carbonate.—The purest ammonium carbonate obtainable was dissolved in water and then distilled once, using a silica condenser.

Ammonium Formate.—A.R. formic acid was distilled once, using a silica condenser ground into a litre pyrex flask, and then neutralised with a pure ammonia solution prepared by passing pure ammonia into freshly prepared distilled water.

Calcium Oxide.—A.R. calcium nitrate was dissolved in water and boiled with lime to remove traces of iron which might be present as impurity. The solution after filtration through a sintered Jena glass Gooch crucible was acidified with nitric acid and the nitrate then three times recrystallised. The calcium nitrate was then converted into carbonate by the addition of ammonium carbonate, and the pure dry carbonate was then packed into a large porcelain boat and heated at about 1100° C. in an atmosphere of pure hydrogen. Before heating, the surface of the carbonate was made into a series of depressions, and in this way there was prepared a boat of lime suitable for the fusion of small silver buttons.

Silver.—Pure silver, prepared by the reduction with ammonium formate of silver nitrate which had been eight times crystallised from the purest water, was fused on boats of pure lime in an atmosphere of pure hydrogen (Richards and Hönigschmid, *loc. cit.*).

As a test of the purity of the silver, the mother-liquors from the sixth crystallisation were used to provide a second sample of silver. If these

samples yield the same ratio $2Ag : CaCl_2$ with pure calcium chloride, this may be taken as convincing proof of the purity of both samples of the metal.

Extraction of Calcium from the Minerals and Preparation of Pure Calcium Chloride.

Since the mineral contains only 0·20 per cent. of calcium and at least 80 grams have to be obtained, it is clear that sodium carbonate fusion as a method of extraction would be exceedingly cumbersome. A recent article in the patent literature by Calcagni (1930) describes how potassium and aluminium may be extracted from leucite by the action of nitric acid. A method of removing potassium must remove the Ca^{41} produced from it, and since there is a possibility of the preferential extraction of Ca^{41} by this procedure, the effect of various acids on the mineral was tried. By using three parts of constant-boiling hydrochloric acid to one part of the pulverised rock, it was found possible to extract 30 per cent. of the calcium by boiling the mixture gently for six hours. The other acids gave less satisfactory results. Enough mineral (about two hundredweights) to yield 180 grams crude calcium oxalate was treated with hydrochloric acid and, after removal of iron, the oxalate was further purified by precipitating another five times.

The calcium oxalate is now very pure, the magnesium being completely removed. Further, the above procedure was shown by Hönigschmid and Kempter (*loc. cit.*) to lead to the complete removal of traces of barium and strontium, so that even if the original calcium oxalate had contained traces of these elements they would now be absent in the final product. The oxalate was then converted into the oxide by heating to 700° in platinum basins. The oxide was transformed into the nitrate by the addition of pure nitric acid, and the resulting solution was filtered through the Jena glass Gooch crucible.

A trace of titanium is present in the mineral, and a faint possibility exists that the oxalate precipitations may have failed to remove it. The most delicate chemical tests failed, however, to indicate its presence. The solution of calcium nitrate was electrolysed for twenty-four hours, using pure platinum electrodes and a very small current; it was then filtered and the calcium nitrate crystallised five times, using the purest water. From the time of the electrolysis to the production of pure calcium chloride the calcium salts came into contact with nothing but platinum or silica. The pure calcium nitrate was next dissolved in water and calcium carbonate precipitated by adding a slight excess of distilled ammonium carbonate solution. As Richards (*loc. cit.*) pointed out, the well-washed

carbonate, if heated to 300°, is absolutely pure except for a trace of calcium nitrate brought down during the precipitation. The trace of nitrate was removed by two further precipitations of the carbonate from very dilute solution. The carbonate, heated to 300° in platinum basins to remove traces of volatile ammonium salts, was then converted to chloride. The filtered chloride solution was evaporated in a dust-free atmosphere, and the crystals of calcium chloride were then dried by placing in a desiccator containing lime and evacuated by means of a Hyvac pump. This last filtration is very necessary, for in spite of all precautions an extremely small amount of dust may have found its way into the preparation. The filtering medium was pure, finely divided platinum contained in a platinum Gooch crucible.

For the reasons given above, another sample of calcium chloride was prepared in a similar way from the calcium nitrate occurring in the mother liquors from the third crystallisation. By leaving the calcium chloride in the vacuum desiccator for a few weeks at a temperature below its transition point, 29°, the substance received a preliminary drying which enables it to be heated and fused, without spattering, during the atomic weight determinations. During all these operations the greatest care was taken to exclude dust and the various gases present as impurities in the atmosphere; in the case of the carbonate this is especially important, and it was preserved in a platinum basin, in a desiccator containing lime made from the purest marble.

In order to obtain calcium suitable for preliminary and comparative atomic weight determinations, cleaned selected marine shells from the Eden estuary, Fifeshire, and recent detrital coral limestone from Bermuda were crushed, incinerated, and treated with hydrochloric acid. By a method similar to that mentioned above, two samples of calcium chloride from each source were obtained. Sea-shells and coral limestone were chosen to obtain what might be called representative modern calcium. Calcium minerals, such as Iceland spar, although of comparatively recent origin, might at some previous time have been in close contact with potassium-rich minerals, and as a result might have been appreciably contaminated with Ca^{41} formed by the disintegration of K^{41}. During the formation of the calcium deposit this Ca^{41} isotope would naturally settle out with the ordinary calcium, and might influence the atomic weight significantly. Within the waters of the oceans, however, where the proportion of potassium to calcium is relatively small, this excessive introduction of Ca^{41} would be prevented. Even if all the oceanic potassium were introduced at the formation of the oceans, about 2000 million years ago, the marine organisms would build up an "average

modern calcium" in which the influence of Ca^{41} on the atomic weight is absolutely negligible.

Melting and Weighing of the Calcium Chloride.

The apparatus employed for the fusion of the chloride was similar to the "Harvard bottling apparatus" of Richards and Wells (1905). The partially dehydrated calcium chloride, contained in a platinum boat, was completely dried, fused in atmospheres of nitrogen and hydrochloric acid, and prepared for weighing according to the method of these investigators.

After weighing, the deviations from neutrality of the fused calcium chloride solutions were determined by colorimetric comparison with a solution of neutral calcium chloride of the same concentration. Standard potassium hydroxide, nitric acid, and aqueous methyl red were employed in these determinations.

Precipitation and Gravimetric Titration.

The exactly equivalent amount of silver was dissolved in nitric acid, and the diluted solution slowly added to the chloride solution contained in a 3-litre Erlenmeyer flask fitted with a ground-in stopper. After standing over night in the dark room the mixture was violently agitated, the flask cooled in ice for twenty-four hours, and the end point determined nephelometrically (for experimental details, see Richards and Wells, *loc. cit.*).

Experimental Results.

Table I.—Calcium from Recent Coral Limestone.

Sample of Chloride.	Sample of Silver.	Corr. Weight of Chloride.	Corr. Weight of Silver.	Atomic Weight.
A	A	1·77727	3·45491	40·077
	A	1·82493	3·54743	40·080
	A	1·81606	3·53030	40·077
B	A	1·74543	3·39311	40·074
	A	1·75771	3·41695	40·075

Table II.—Calcium from Marine Shells.

Sample of Chloride.	Sample of Silver.	Corr. Weight of Chloride.	Corr. Weight of Silver.	Atomic Weight.
A	A	2·02793	3·94230	40·074
	A	2·09760	4·07770	40·074
	B	2·23959	4·35369	40·075
	A	2·18660	4·25062	40·077
B	B	2·13950	4·15897	40·079
	B	2·04200	3·96947	40·079

TABLE III.—CALCIUM FROM PEGMATITE (PORTSOY).

Sample of Chloride.	Sample of Silver.	Corr. Weight of Chloride.	Corr. Weight of Silver.	Atomic Weight.
B	B	1·70015	3·30465	40·089
	B	1·78487	3·46928	40·090
	A	1·74779	3·39721	40·090
	A	1·69538	3·29562	40·087
A	B	1·87366	3·64188	40·089
	B	2·07253	4·02853	40·086

TABLE IV.—CALCIUM FROM PEGMATITE (RHICONICH).

Sample of Chloride.	Sample of Silver.	Corr. Weight of Chloride.	Corr. Weight of Silver.	Atomic Weight.
A	B	1·94278	3·77612	40·092
	B	1·98782	3·86364	40·093
	A	1·88677	3·66715	40·095
	B	1·96884	3·82687	40·090
B	B	2·19803	4·27222	40·093
	A	2·17033	4·21850	40·090

Samples, A and B, of silver were obtained from silver nitrate which had been six and eight times crystallised respectively. In the case of the chloride A and B were derived from the third and fifth crystallisations of the nitrate.

The results in all the series of determinations were consistent, and the two samples of silver gave results essentially identical, thus establishing the purity of the metal. Samples A and B of the chloride in each series yielded values of the atomic weight concordant to within the limit of experimental error. This may be taken as proof of the purity of all the calcium chloride used in these determinations.

TABLE V.

Sources of Calcium.	Atomic Weight.	Probable Error.
Coral limestone	40·077	±0·0007
Marine shells	40·076	±0·0008
Portsoy rock	40·089	±0·0004
Rhiconich rock	40·092	±0·0006

The estimates of the atomic weight of normal calcium are very close to the value 40·074 put forward by Richards and Hönigschmid in 1910, but differ quite appreciably from the number 40·084 advanced by Hönigschmid and Kempter in 1931. These latter investigators purified their ordinary calcium by a method which, as they themselves pointed out, failed to remove the last traces of strontium. There is a possibility, therefore, that the value 40·084 is slightly high because of the small content of either strontium or barium. The calcium which gave the values 40·076

and 40·077 was purified by repeated precipitation of the oxalate, a procedure which Hönigschmid and Kempter proved to eliminate all strontium and barium. The slightly high value obtained by them could also be explained by assuming that at some geological period before the formation of the marble which yielded the atomic weight of 40·084 the calcium content had been associated with potassium and had thus acquired a certain percentage of Ca^{41}. Strength is given to this supposition by the work of Allison and Goslin (1932), who detected Ca^{41} in six out of fourteen commercial salts which he examined by his magneto-optic method.

The atomic weights of the "heavy" calcium are 40·092 for the Rhiconich rock and 40·089 for the Portsoy rock. These two samples of calcium were sent for analysis to Professor Allison, who, as a result of the examination, reported that in them there were percentages of Ca^{41} far greater than had ever before been detected in calcium salts which had been tested by his magneto-optic method. Professor Allison further examined them for traces of barium and strontium, and his analysis revealed that if these were present they were in quantities less than one in a million. Accordingly it may be assumed with almost complete certainty that the increases of 0·013 and 0·016 in the atomic weights of the calcium obtained from Portsoy rock and Rhiconich rock respectively are to be attributed to the presence of the isotope with mass 41.

This assumption gains further support from additional atomic weight determinations carried out with calcium to which 0·5 per cent. of strontium and 0·5 per cent. of barium had been added, and which was purified by the above methods. As the mean of four determinations the atomic weight was increased by only 0·003 unit above the mean value 40·076 obtained in the previous series of experiments, thereby proving that the large increases of 0·013 and 0·016 unit obtained with a rock calcium which contained before purification no detectable quantity of barium or strontium could not be ascribed to the presence of these substances as impurities.

The increase in the atomic weight may be used to calculate two limiting values of the half-period of the K^{41} isotope under one or other of the two following assumptions:—

(1) That the 30 per cent. extraction obtained in the treatment of the rock with acid removed all the Ca^{41} in the mineral.

(2) That the extraction removed only 30 per cent. of the total amount of Ca^{41} present in the rock.

In a preliminary communication of this research (Kendall, Smith, and Tait, 1933) it was assumed, in making the necessary calculations, that the *Geological Survey* analyses of the two pegmatites (see p. 91) could

be utilised as applicable to the materials actually used. Through the kindness of Professor Arthur Holmes, of the University of Durham, to whom a sample of the Rhiconich mineral had been sent, it was learned, however, that this assumption was not warranted. Pegmatites are notoriously variable in composition from point to point, and the Rhiconich mineral had not been hand-picked, so that it was obviously essential to have direct analyses made on the samples employed in the research. Analyses made by Dr Winifred Guthrie in this laboratory on the thoroughly mixed crushed material from several hundredweights of rock gave the following results:—

Portsoy Pegmatite.	I.	II.	III.
K_2O	8·48	8·55	8·51
CaO	0·27	0·30	..

Rhiconich Pegmatite.	I.	II.
K_2O	8·13	7·90
CaO	0·53	0·53

Independent analyses made by Dr A. W. Groves, of the Royal College of Science, on the same material showed:

	K_2O.	Na_2O.	CaO.
Portsoy pegmatite	7·70	3·05	0·29
Rhiconich pegmatite	7·95	2·54	0·57

The agreement, it will be seen, is extremely satisfactory throughout, except in the case of potassium in the Portsoy pegmatite. The discrepancy here, however, is not significant, and for our immediate purposes the rounded-off figure K_2O 8·0 per cent. may be utilised for both rocks, while the CaO values may be taken as 0·28 per cent. (Portsoy) and 0·55 per cent. (Rhiconich).

Using these figures, and assuming that the approximate ages of the Portsoy and Rhiconich deposits are 400 million years and 1000 million years respectively (see pp. 90–91), we arrive at the following limiting values for the half-period of the K^{41} isotope:—

	Upper Limit.	Lower Limit.
Portsoy	$1{\cdot}6 \times 10^{11}$ years.	$0{\cdot}5 \times 10^{11}$ years.
Rhiconich	$1{\cdot}6 \times 10^{11}$ years.	$0{\cdot}5 \times 10^{11}$ years.

The concordance for the two minerals is clearly most satisfactory, and in view of the fact (see p. 94) that it is probable that practically all the Ca^{41} was removed by the acid extraction, the upper limit may be regarded as the more likely value. It is of interest to note that this upper limit is practically identical with the revised result of Holmes and Lawson, namely, 1×10^{11} years.

Summary.

The atomic weights of samples of "abnormal" calcium extracted from two very old potassium-rich minerals have been determined and compared with those obtained with calcium of recent marine origin. Calcium from Portsoy pegmatite gave an atomic weight of 40·089; calcium from Rhiconich pegmatite 40·092. The increase above the normal value (40·076–40·077) is ascribed to the presence of Ca^{41} formed by the radioactive disintegration of K^{41}.

From these results a "most probable" value for the half-period of the K^{41} isotope has been calculated, which is in very close agreement with the estimate of 1×10^{11} years put forward by Holmes and Lawson.

In conclusion, we desire to thank Professor James Kendall, at whose suggestion and under whose direction the research was carried out, for his advice and guidance. We wish also to express our gratitude to Emeritus-Professor Sir James Walker for his kindly interest, and to Dr Frederick Walker, of the Department of Geology at the University of St Andrews, for his invaluable aid in the selection of suitable "abnormal" and "normal" calcium sources and in the collection of the large quantities of material necessary for the research. We are indebted, furthermore, to Professor Allison for his kindness in examining our samples by his magneto-optic method, and to Dr Winifred Guthrie for analyses.

We also wish to acknowledge the awards of a Carnegie Research Scholarship (T.T.) and Baxter Physical Science Scholarship (W.W.S.) held by us throughout the work, and a grant from the Moray Fund of the University of Edinburgh.

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IX.—The Photoelectric Thresholds of some Turned Metallic Surfaces.

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Introduction.

The photoelectric threshold is a property which is characteristic of a surface state. Accordingly, with a view to a more complete investigation of a turned metallic surface, the apparent thresholds of some metal surfaces, examined immediately after being turned on a lathe, were determined.

The apparatus used for the measurement of the photoelectric currents was one of great sensitivity, employing the electrometer valve. The small photoelectric currents produced by the action of the light on the metal were made to change the potential existing across a high resistance in the grid circuit of the valve. This change in grid potential caused a corresponding change in the anode current, which was measured by a Paschen galvanometer. A similar apparatus has been used previously by Teegan and Hayes (1933) for the measurement of small currents.

Source of Light.—This consisted of a Cooper-Hewittic Quartz Mercury Vapour Lamp used in conjunction with a Hilger Quartz Monochromator. The lamp was operated from the mains at 230 volts, and about fifteen minutes were allowed for it to settle down into a steady state of illumination.

The Photoelectric Cell.—This was a modification of the type of cell used by H. S. Allen (1906) in experiments on the photoelectric fatigue of metals. The mercury cups were dispensed with, all connections to the cell being soldered. Improvements were made in the shape of the metal grid and in the insulation of the central rod carrying the cathode. The grid was made in the shape of a collecting cylinder, so that it collected electrons given off at all angles from the metal surface. The insulation was raised by surrounding the cathode lead with a cylinder of ebonite, which in turn was surrounded by a cylinder of sulphur. This prevented any leakage through the ebonite, and any surface leakage across the ebonite face at either end was prevented by rings of sulphur. This insulation was tested, and the resistance found to be between 10^{+14} and 10^{+15} ohms.

The Electrometer Valve.—This valve, supplied by the General Electric Co., possesses two characteristic properties. The first is the high insulation—resistance 10^{15} ohms—which surrounds the grid, and the second is that the slope of the characteristic curve is much less than that of an ordinary triode. This latter property demands that a high resistance grid leak of the order 10^{10} ohms be used, if great sensitivity is to be obtained.

High Resistance.—This was constructed from quill glass tubing of 1 millimetre bore approximately, and of length 20 centimetres. The tube was filled with a mixture of xylol and alcohol by suction, and the glass of the tube covered with sealing wax, so that leakage over the glass surface was minimised.

The circuit arrangements are shown in the diagram.

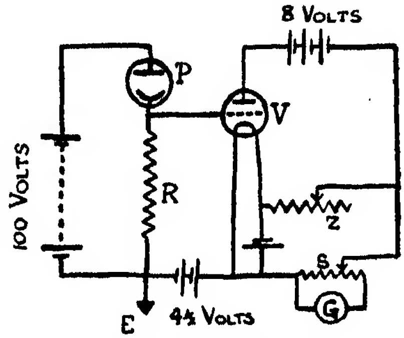

FIG. 1.—Circuit diagram.

P, Photoelectric cell; V, electrometer triode; R, xylol-alcohol resistance; Z, potentiometer; G, Paschen galvanometer; S, galvanometer shunt.

The photoelectric cell, electrometer valve, the xylol-alcohol resistance, and the potentiometer were built up inside a wooden cabinet, which was lined on the inside with sheet tin and earthed. The high resistance was mounted on the sheet tin by two pillars of sealing wax. The grid bias battery was attached to an ebonite rod covered with sulphur and plugged into a space provided for it on the outside of the cabinet. The filament rheostat was immersed in oil, and the air inside the cabinet was kept dry by means of calcium chloride.

When these precautions had been taken, the creep of the galvanometer zero was negligible. Small fluctuations of the spot of light took place, but these were overcome by suspending all high-tension wires in space, reducing mechanical vibrations by placing the cabinet on a stone slab, and thirdly, by keeping the photo-cell airtight.

The voltage on the plate of the valve was 8 volts and that on the grid $4\frac{1}{2}$ volts negative. The filament current was kept at a constant value between 0·08 and 0·09 amperes. The voltage on the grid of the photoelectric cell was 100 volts, obtained from a Milne's Unit.

The smallest current that could be measured with the apparatus can be written in the form

$$\frac{1}{R.s.m.}$$

where R is the value of the xylol-alcohol resistance; *s* the number of scale divisions of the galvanometer per microamp; *m* the mutual conductance of the electrometer triode in microamps per volt.

Now the value of the high resistance used in this investigation was determined by noting the steady deflection produced in a sensitive galvanometer, when the two were in series with a 100-volt battery. The steady deflection was 7 mm., and the sensitivity of the galvanometer could be expressed as $3{\cdot}04 \times 10^{-11}$ amps. per mm. Thus the xylol-alcohol resistance was of the order $4{\cdot}7 \times 10^{11}$ ohms.

The mutual conductance of the valve was 80 microamps per volt, and the sensitivity of the Paschen galvanometer used in the anode circuit was of the order 5×10^{3} mm. per microamp.

If these values be substituted in the above expression it is seen that the apparatus was capable of measuring a current of 6×10^{-18} amperes. However, at such high sensitivity the apparatus was too difficult to control, becoming somewhat unstable. Also, the galvanometer needle was too slow in its movement to give accurate readings, and the potentiometer system was too delicate to be successfully manipulated. In practice, therefore, the sensitivity was never allowed to exceed 10^{-16} amps. per mm., this value being found satisfactory both from a sensitivity and a workable point of view.

In the determination of the photoelectric currents the following procedure was adopted. The metal plate, in the form of a disc of diameter $1\frac{3}{8}$ in., was turned down on a lathe with a clean cast-steel tool, using no lubricant whatsoever. The metal was transferred at once to the cell, which was kept in darkness. The initial anode current flowing was balanced out by means of the potentiometer, Z. A shutter which could be operated from a distance was opened, and light of known frequency was allowed to fall on the metal plate through the quartz window of the photo-cell. The galvanometer reading was noted for the several spectral lines used. These were 2540 A, 2650 A, 2760 A, 2804 A, 2960 A, 3125 A, 3350 A, 3650 A, and 4050 A. They correspond approximately to the strong lines in the mercury arc spectrum.

Intensity Distribution of Incident Radiation.

In order that the photoelectric currents produced by the different wave-lengths might be transformed into currents per unit intensity, the energy distribution throughout the spectral region employed was determined. This was done by causing the monochromatic radiation from each of the above spectral lines to fall on a sensitive thermopile, which was connected to the Paschen galvanometer. The junctions of the

thermopile were of bismuth and silver, and the instrument was mounted in a special recess in the telescope of the monochromator. The recess was evacuated and kept airtight; also, it was surrounded externally by a polished tin box, which was packed inside with worsted. These precautions ensured that the creep of the zero was negligible.

The following table gives the relative intensities of the lines measured, that of 2540 A being taken arbitrarily as 100.

TABLE I.—RELATIVE INTENSITIES OF SPECTRAL LINES.

Wave-length	Intensity	Wave-length	Intensity
2540 AU	100	3125 AU	284
2650 ,,	74·8	3350 ,,	67·6
2760 ,,	39·6	3650 ,,	548
2804 ,,	40·3	4050 ,,	298·4
2960 ,,	104·4		

The calibration of the thermopile permits the above intensity readings to be turned into absolute measurements of energy. From data sent with the thermopile it was calculated that an energy of 97 microwatts per square cm. would cause a current of 0·295 microamps to flow through the galvanometer. From this it was calculated that the energy from the line 2540 A, represented in Table I as 100, was 1·46 microwatts.

By means of the results of Table I the values of the current per unit intensity at each wave-length were determined. These currents were plotted against the respective wave-lengths for each of the metals examined. These metals were copper, silver, antimony, bismuth, tin, lead, nickel, iron, zinc, aluminium, brass, and cast-steel. The spectral distribution curves obtained, some of which are shown in fig. 2, were extrapolated to zero current, and the corresponding wave-length taken as the apparent threshold of the metallic surface.

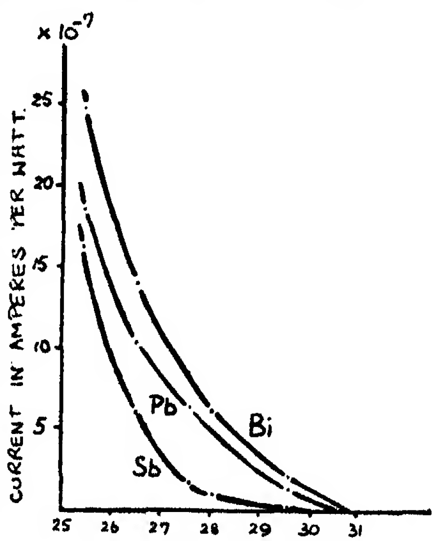

FIG. 2.—Photoelectric thresholds for turned metal surfaces. Wave-length in 10^{-6} cm.

Table II below contains a list of the apparent thresholds in Angstrom units and in volts for each metal, as determined from the above curves.

TABLE II.—THRESHOLD VALUES FOR TURNED SURFACES.

Metal	Thresholds AU.	Thresholds Volts.	Metal	Thresholds AU.	Thresholds Volts.
Copper	2985	4·13	Nickel	3125	3·95
Silver	3200	3·85	Iron	2980	4·14
Antimony	2996	4·12	Zinc	3225	3·825
Bismuth	3075	4·01	Aluminium	3740	3·30
Tin	3000	4·115	Brass	3025	4·08
Lead	3060	4·03	Cast-Steel	2916	4·23

No previous determinations of the threshold values for freshly turned metallic surfaces have been made, so that these results cannot be compared with any obtained by previous workers. Table III, however, contains threshold values for some metals examined in the partially out-gassed state. This means that the metals have been partially denuded, by some form of vacuum treatment, of gases occluded by the metals. The reason for giving this table is to compare thresholds for a partially out-gassed surface with that of the freshly turned surface of the same metal.

TABLE III.—PREVIOUS THRESHOLDS FOR PARTIALLY OUT-GASSED METALS.

	Werner (1914).	Welch (1928).	Parmeley (1927)	Kadesch and Hennings (1916).
Copper	..	2955 A	..	3000 A
Silver	3150 A	..	..	..
Bismuth	3050 A	..	2835 A	..
Nickel	2700 A	3040 A	..	..
Iron	..	3155 A	..	3000 A
Aluminium	..	..	..	3652 A
Zinc	..	3182 A	..	..
Tin	..	..	..	3000 A

Lead does not seem to have been examined in either the partially or totally out-gassed state. However, previous determinations of the threshold for a lead surface without any out-gassing treatment have been made, the latest results being 2980 A (1924) and 3110 A (1928). No determinations of thresholds for antimony, brass, and cast-steel in any state seem to have been made previous to this investigation Thresholds for the metals silver, nickel, iron, and tin in the totally out-gassed state have been determined, and all are to be found in the spectral region $\lambda\lambda$ 2600–2740 A.

It is seen from a comparison of Tables II and III that the thresholds for metal surfaces in the turned state approximate to those for the same metals when the surface is partially out-gassed. The thresholds for the

turned surface, however, are at much greater wave-lengths than are the thresholds for the same metals in the totally out-gassed state. This leads to the natural conclusion that the potential barrier existing at the surface of a metal when it is in the turned state is similar to that existing when the surface is in the partially out-gassed state, but not as high as the barrier at the surface when the metal is in the totally out-gassed state. This suggests that the occluded gases in a metal can be removed by cutting away the existing surface layer, but that this process will not remove in entirety the occluded gas. Bearing the above in mind and remembering that the threshold is a property characteristic of the surface, the claim that the turned state is similar to the partially out-gassed state would appear to be justified. Thus a turned surface is one which is partially denuded of occluded gas. This conclusion is also borne out by the following consideration. In addition to any gas adsorbed on the metal surface, there is present a certain amount of absorbed gas diffused throughout the metal. When a new crystalline surface is exposed, by the turning process, the only occluded gas on the new surface is a percentage of the total absorbed gas, whereas the surface layer cut away contains not only the percentage of absorbed gas but also the adsorbed gas. Thus the new surface contains less occluded gas than the old surface.

The photoelectric fatigue of a metal surface in air will depend therefore not only on the amount of adsorbed gas, but also on the absorbed gas present in the metal. The relative importance of these two factors in the fatigue effect has not been determined.

SUMMARY.

(1) Long wave-length photoelectric thresholds have been determined for some metal surfaces in the turned state, using the valve electrometer.

(2) The thresholds for the metals copper, silver, antimony, bismuth, tin, lead, nickel, iron, zinc, aluminium, brass, and cast-steel in the turned state are 2985 A, 3200 A, 2996 A, 3075 A, 3000 A, 3060 A, 3125 A, 2980 A, 3225 A, 3740 A, 3025 A, and 2916 A respectively.

(3) The above thresholds are found to approximate to those for the same metals in the partially out-gassed state. It is concluded that a turned surface is one which is partially denuded of occluded gases.

In conclusion, the writer wishes to express his thanks to the Carnegie Trust for a scholarship to enable him to carry out this work, and to Professor H. S. Allen, F.R.S., for his helpful criticism and valuable aid throughout the investigation.

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X.—Note on the Electron Configurations p^2s, p^4s. By Robert Schlapp, M.A., Ph.D., University of Edinburgh.

(MS. received February 26, 1934. Read June 4, 1934.)

In his original paper on the theory of complex spectra Slater (1929) calculated, as one of his examples, the relative positions of the multiplets ^3P, ^1D, ^1S, arising from a configuration of two equivalent p electrons p^2. The intervals between these multiplets, in the order written, were found to be in the ratio of 2 : 3. The same result was shown to hold for p^4. Slater's method depends on setting up wave-functions for the atom by combining suitably the wave-functions of single electrons in a central field. With these atomic wave-functions the mean values of the electrostatic energy are calculated for the various multiplets. These mean values involve integration over angular co-ordinates, which can be performed, as well as integrations containing the unknown radial functions, which appear as parameters in the final result. The same method was subsequently applied (Condon and Shortley, 1931) to the configurations p^2s, p^4s, and extended (Johnson, 1932) to include in addition to the electrostatic energy the energy of the magnetic interaction between the orbits and spins, with which Slater was not concerned.

It was pointed out to the writer by Professor J. H. Van Vleck that instead of using Slater's method to compute the electrostatic energies afresh, it is simpler in this case to use the known energies for the core p^2, p^4 (Slater, 1929), together with the idea, due to Dirac (1930, p. 214), that the electrostatic exchange interaction of two electrons is formally equivalent to a magnetic spin-spin coupling between them. The coupling between the s electron, spin $\mathbf{s}$, and each of the core electrons, spin $\mathbf{s}_i$, is proportional to the scalar product $(\mathbf{s}_i \cdot \mathbf{s})$. This may be summed over the core electrons, since they are equivalent, so that the electrostatic exchange energy is a multiple of $(\mathbf{s}' \cdot \mathbf{s})$, where $\mathbf{s}'$ is the spin of the core.

This way of representing the interaction holds, in the simple form stated above, only when the electron outside the core is an s electron. Since the s wave-function is spherically symmetrical, an orbital degeneracy of the core cannot affect the interaction; more precisely, the matrix of the interaction energy has no components between core states of different m_l, since here $m_l = M_L$. A striking example of the inapplicability of the

rule in its unmodified form is Slater's (1929) result that the energies in pp' depend on three parameters instead of one.

Quantum numbers referring to the core p^2 or p^4 as a whole will be denoted by accented small letters, and those referring to the whole atom by capital letters. Note that $L = l'$ and $J = j' \pm \frac{1}{2}$. We evaluate the diagonal elements of the exchange interaction energy, proportional to $(\mathbf{s}' \cdot \mathbf{s})$, between the s electron and the core in a state j', l', s', when the atom is in the state J. For the mean value of cos $(\mathbf{s}\,\mathbf{s}')$ we write as usual cos $(\mathbf{s}\,\mathbf{j}')$ cos $(\mathbf{j}'\,\mathbf{s}')$, and use the familiar expressions for "quantum cosines" (Pauling and Goudsmit, 1930, p. 55); we thus obtain for the diagonal elements in question the expression

$$Y\{J(J+1) - j'(j'+1) - \tfrac{3}{4}\}\{l'(l'+1) - j'(j'+1) - s'(s'+1)\}/j'(j'+1),$$

where Y is a parameter measuring the strength of the coupling. The following table gives the value of this expression for the five core states ${}^{2s'+1}l'_{j'}$ given at the head of the table, and the three possible J-values, written at the left. The last line contains the electrostatic energies of the core states, as calculated by Slater (1929), X being a parameter measuring the strength of the coupling between the electrons of the core. The state ${}^3P$ has been taken as the origin of energy. All the energies are arbitrary to the extent of an additive constant, which has been omitted, as we are concerned only with energy differences. Since the total angular

Core States	${}^3P_2$	${}^1D_2$	${}^3P_1$	${}^3P_0$	${}^1S_0$			
$J = \frac{5}{2}$	$-2Y$	0				${}^4P_{5/2}$	${}^2D_{5/2}$	
$\frac{3}{2}$	$3Y$	0	$-Y$			${}^4P_{3/2}$	${}^2P_{3/2}$	${}^2D_{3/2}$
$\frac{1}{2}$			$2Y$	0	0	${}^4P_{1/2}$	${}^2P_{1/2}$	${}^2S_{1/2}$
Core Energies	0	2X	0	0	5X			

momentum J of the atom is a constant of the motion whatever the internal interactions may be, the secular determinant is diagonal in J, so that it breaks up, as the table shows, into three factors, corresponding respectively to the three values of J. $J = 5/2$ gives a quadratic, and $J = 3/2$, $1/2$, each give a cubic determinantal equation, whose roots are the energies of the atomic states shown at the right of the table. The three determinants are written out in full a little further on, the core states to which the diagonal elements refer being noted at the left of each determinant. Up to this point we know only the diagonal elements, which are those in the table above. The non-diagonal elements, proportional to Y, are as yet undetermined. There are of course no non-diagonal elements in X. The determination of the elements involving A, which describe the orbit-

spin interaction, will be discussed later. For the moment we are neglecting this interaction, so that $A=0$. We then see that each of the determinants again breaks up into factors, for the electrostatic energy between the core and the s electron (parameter Y) has no elements between states of different l'. This is because interaction with the spherically symmetrical s electron cannot affect the constancy of the orbital angular momentum l' of the core. In consequence both roots of the quadratic and one root of each of the cubic equations fall apart. The non-diagonal elements in the remaining quadratic factors, which are proportional to Y, and arise because interaction with the s electron spoils the constancy of j', may be determined by the condition that the electrostatic energy for given L, S, is independent of J, since we are neglecting orbit-spin interaction. Thus the three determinantal equations for $J=5/2, 3/2, 1/2$ must have one root in common, and this must be ^{4}P, while another root (^{2}D) must be common to the first two, and still another (^{2}P) must be common to the last two. These conditions are sufficient to determine the non-diagonal elements $\sqrt{5}Y$, $2\sqrt{2}Y$, shown in the determinants, which then lead to the following energy values for p^2s or p^4s in Russell-Saunders coupling $(A=0)$:—

$$W(^4P) = -2Y, \qquad W(^2P)=4Y, \qquad W(^2D)=2X, \qquad W(^2S)=5X.$$

This result is equivalent to that obtained (Condon and Shortley, 1931) by applying Slater's method to the whole configuration.

It is easy to extend this result to allow for orbit-spin interaction. Since the s electron has no orbital angular momentum, it is only necessary to incorporate what is essentially Goudsmit's (1930) calculation of the orbit-spin interaction in p^2 or p^4. This interaction, given (in the case of p^2) by $a(\mathbf{l}_1 \cdot \mathbf{s}_1)+a(\mathbf{l}_2 \cdot \mathbf{s}_2)$, where a is a constant, does not impair the diagonality in J, but introduces into the secular determinant elements non-diagonal in l' or s'. These elements will, however, not connect different values of j', since the constancy of the corresponding angular momentum is unaffected by the interaction. In addition there will be new diagonal elements, equal to $\frac{1}{2}A\{j'(j'+1)-l'(l'+1)-s'(s'+1)\}$, where A is the usual constant of the orbit-spin interaction, and has the value $\frac{1}{2}a$ for p^2 and $-\frac{1}{2}a$ for p^4. The non-diagonal elements are then determined so as to give the known energy values (Pauling and Goudsmit, 1930, p. 161) of p^2 or p^4 in j_1-j_2 coupling, $(X=0)$, namely, a, $-\frac{1}{2}a$, for $j'=2$, $-\frac{1}{2}a$ for $j'=1$, and a, $-2a$, for $j'=0$.

In this way we obtain the following secular determinants for the three values of J, whose roots give the energy levels W of the configurations p^2s (A positive) or p^4s (A negative), in terms of three arbitrary parameters

X, Y, A, specifying the various interactions. The secular equations may readily be shown to be equivalent to those given by Johnson (1932):

$$J=\tfrac{5}{2} \qquad \begin{array}{c|cc|} {}^3P_2 & -2Y+A-W & \sqrt{2}A \\ {}^1D_2 & \sqrt{2}A & 2X-W \end{array}$$

$$J=\tfrac{3}{2} \qquad \begin{array}{c|ccc|} {}^3P_1 & -Y-A-W & \sqrt{5}Y & 0 \\ {}^3P_2 & \sqrt{5}Y & 3Y+A-W & \sqrt{2}A \\ {}^1D_2 & 0 & \sqrt{2}A & 2X-W \end{array}$$

$$J=\tfrac{1}{2} \qquad \begin{array}{c|ccc|} {}^3P_1 & 2Y-A-W & 2\sqrt{2}Y & 0 \\ {}^3P_0 & 2\sqrt{2}Y & -2A-W & 2\sqrt{2}A \\ {}^1S_0 & 0 & 2\sqrt{2}A & 5X-W \end{array}$$

The present method supplements Goudsmit's (1930) treatment of the ideal case ${}^3P+s$, where the ${}^3P$ of p^2 or p^4 is isolated from ${}^1D$ and ${}^1S$. The levels of p^3s, or in fact of any configuration involving an s electron and a core of equivalent electrons, can readily be found in the same way.

We now consider the Zeeman effect, in weak fields, of the terms (LSJ). We first transform the energy matrix from the $(j's)$ system used hitherto to the (LS) system appropriate to Russell-Saunders coupling, in which the whole electrostatic energy is diagonal. This is done in the usual way by applying the unitary transformation with numerical coefficients which will bring the terms $\sqrt{5}Y$ and $2\sqrt{2}Y$ on to the diagonal. In the resulting secular determinants only terms in A appear off the diagonal.

The effect of a weak magnetic field H applied along the z-axis is merely to add to the diagonal elements in the (LS) representation terms $\beta M g H$, where β is the Bohr magneton, M the projection of J on the z-axis, and g is Landé's g-value of the diagonal element. For the additional energy due to the magnetic field is $\beta(L_z+2S_z)H$, and this is diagonal in L and S, but has elements $\Delta J=\pm 1, 0$. The elements $\Delta J=0$ are simply $\beta M g H$; the non-diagonal elements are also known, but may be neglected so long as the field is not strong enough to produce a Paschen-Back effect of the multiplet structure. To find the value g' of the g-factor for any values of the parameters X, Y, A, it is now merely necessary to replace W by $W_0+\beta M g' H$, where W_0 satisfies the secular equation for the appropriate value of J with $H=0$, and solve approximately for g'. In this way we obtain the values:

$$J=\tfrac{5}{2}: g'=\frac{2}{5}\,\frac{7W_0-8X+6Y-3A}{2W_0-2X+2Y-A},$$

$$J=\tfrac{3}{2}: g'=\frac{2}{15}\,\frac{29W_0^2-W_0(46X-2Y+2A)+64XY-112Y^2+4AX-28AY-31A^2}{3W_0^2-4W_0X+4XY-12Y^2-4AY-3A^2},$$

$$J=\tfrac{1}{2}: g'=\frac{2}{3}\,\frac{8W_0^2-W_0(25X+20Y-16A)+70XY-35AX-24Y^2-12AY-6A^2}{3W_0^2-W_0(10X+4Y-6A)+10XY-15AX-8Y^2-4AY-2A^2}.$$

The configurations p^2s, p^4s occur often in arc and spark spectra, arising by excitation of one or more of the electrons in a configuration p^3, p^4, p^5, or p^6, or of an s electron in s^2p or s^2p^3. In most cases only a few of the eight terms have been identified; often there are no intercombinations between the doublet and quartet terms, so that their relative positions cannot be determined. An extensive comparison with experiment would be out of place in this note, but as an example we may give the observed and calculated values for the terms of the configuration $4p^25s$ in the arc spectrum of arsenic (Bacher and Goudsmit, 1932, p. 53). All the terms have been identified with certainty except $^2S_{\frac{1}{2}}$. We have tentatively identified this term with one observed at 19617 cm.$^{-1}$ referred to $^4P_{\frac{5}{2}}$ as origin, which has $J=\frac{1}{2}$ and the right parity. The method of fitting has been to make the intervals between the centres of gravity of terms with the same J, given by the diagonal sums in the secular determinants, and also the interval between the two levels $J=\frac{5}{2}$ agree with experiment. This leads to the values $X=3884$, $Y=309$, $A=786$, all in cm.$^{-1}$, and the following comparison between observed and calculated levels :—

	$^4P_{\frac{1}{2}}$	$^4P_{\frac{3}{2}}$	$^4P_{\frac{5}{2}}$	$^2P_{\frac{1}{2}}$	$^2P_{\frac{3}{2}}$	$^2D_{\frac{5}{2}}$	$^2D_{\frac{3}{2}}$	$^2S_{\frac{1}{2}}$
Obs.	−2204	−1288	0	237	1707	7937	7917	(19617)
Calc.	−2158	−1271	0	163	1671	7957	7917	19645

The agreement is reasonable; even the inverted ^2D is reproduced. By varying the method of fitting, the agreement can be made to appear much better, but no attempt has been made to do this because of the uncertainty of the $^2S_{\frac{1}{2}}$ term, which in any case is probably strongly perturbed by other configurations.

If we use the above value of A to determine the screening constant σ we find $\sigma=17{\cdot}9$. The value from X-ray spectra is about 17, which is in satisfactory agreement. It must, however, be remembered that A is very sensitive to changes in σ, as the expression for A involves $(Z-\sigma)^4$.

Measurements of the g-values in certain spectra involving p^2s or p^4s also exist, but as these vary within narrow limits as the coupling changes they are not very suitable for testing the formulæ.

The idea of using Dirac's model of the electrostatic interaction quantitatively in connection with atomic spectra, is due, as has been mentioned, to Prof. Van Vleck (1934), whom I should like to thank for suggesting to me the subject of this note.

SUMMARY.

The secular equations for the energy levels of the configurations p^2s, p^4s, inclusive of the orbit-spin interaction, are set up using Dirac's result that the electrostatic exchange energy of two electrons is formally equivalent to a magnetic coupling between their spins. The equations are expressed in terms of three parameters, giving respectively the coupling between the equivalent electrons, the coupling between the s electron and the core, and the orbit-spin coupling. The Landé g-values for the levels are found as functions of these parameters. As an example, the calculated energy levels are compared with those observed in the arc spectrum of arsenic. The agreement is reasonable.

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(*Issued separately July* 5, 1934.)

XI.—Graphical Classification of Carbonaceous Minerals: The Mineral Oils. By Professor Henry Briggs, D.Sc., Ph.D., University of Edinburgh. (With Chart.)

(MS. received January 12, 1934. Read June 4, 1934.)

In two previous communications to the Society (Briggs, 1931, 1932), the graphical method, based on the ultimate analysis, was applied to the classification of carbonaceous minerals, and particularly to the elucidation of the process of "development" of those minerals—a process that involves the progressive histolysis of the primitive plant offal, and a progressive enrichment in carbon and impoverishment in oxygen of the mineral substances produced from it. Almost entirely, attention in those papers was directed to the solid minerals, namely, to the constituents of common coals and to the species severally known as torbanites, oil shales, cannels, and sub-cannels. On the present occasion, however, interest is concentrated on the petroleums. My purpose is to ascertain to what extent the graphical method is able to throw light on the origin and manner of development of the oils.

The analyses of a number of crude oils were included in a graph (fig. 2) of my first (1931) paper on this subject, though reference to them in the text was limited to a single paragraph. All that was done at that time, indeed, was to remark that the points representing the oil analyses seemed to adhere fairly well to one or other of two parallel lines, and that the trend of those lines was entirely different from that of the corresponding lines of the oil shales and fuels. A few analyses of fossil resins and resinoid substances were plotted on the graph in question, but only with the object of showing a similarity in composition between those substances and the kerogen of oil shale. The analyses of the oils and resinoids have now been transferred to the chart accompanying the present communication; they are supplemented by other analyses of mineral resins and waxes that have been collected recently from various publications. As before, all analyses have been referred to the basis $C+H+O=100$ per cent.

It is generally conceded that the only theories relating to the origin of petroleum that are worthy of consideration are those ascribing its formation to the decomposition of organic substances; and though in some instances animal matter may have played a part in the process, the accepted

opinion is that plant life is *fons et origo* in regard to mineral oil. The chart provides additional evidence in favour of that view.

Against the theory of the vegetable origin of oil stands the argument that, given sufficient time, vegetable refuse buried beneath other beds becomes coal; that every gradation of that process is known; that the intermediate products, peat and lignite, are plentiful; but that no one has been able to define with certainty the kind of vegetable matter that yields oil or to exhibit the stages of the operation. The chart does not furnish a final answer to these considerations; but it strongly suggests that there were no essential differences between the material that was the origin of coal and the material that was the origin of oil. It points, indeed, to the difference in the eventual products as being due to diverging courses of development, and to the probability of those courses—towards coal on the one hand and oil on the other—having been decided at a relatively early stage in the degradation of the plant refuse.

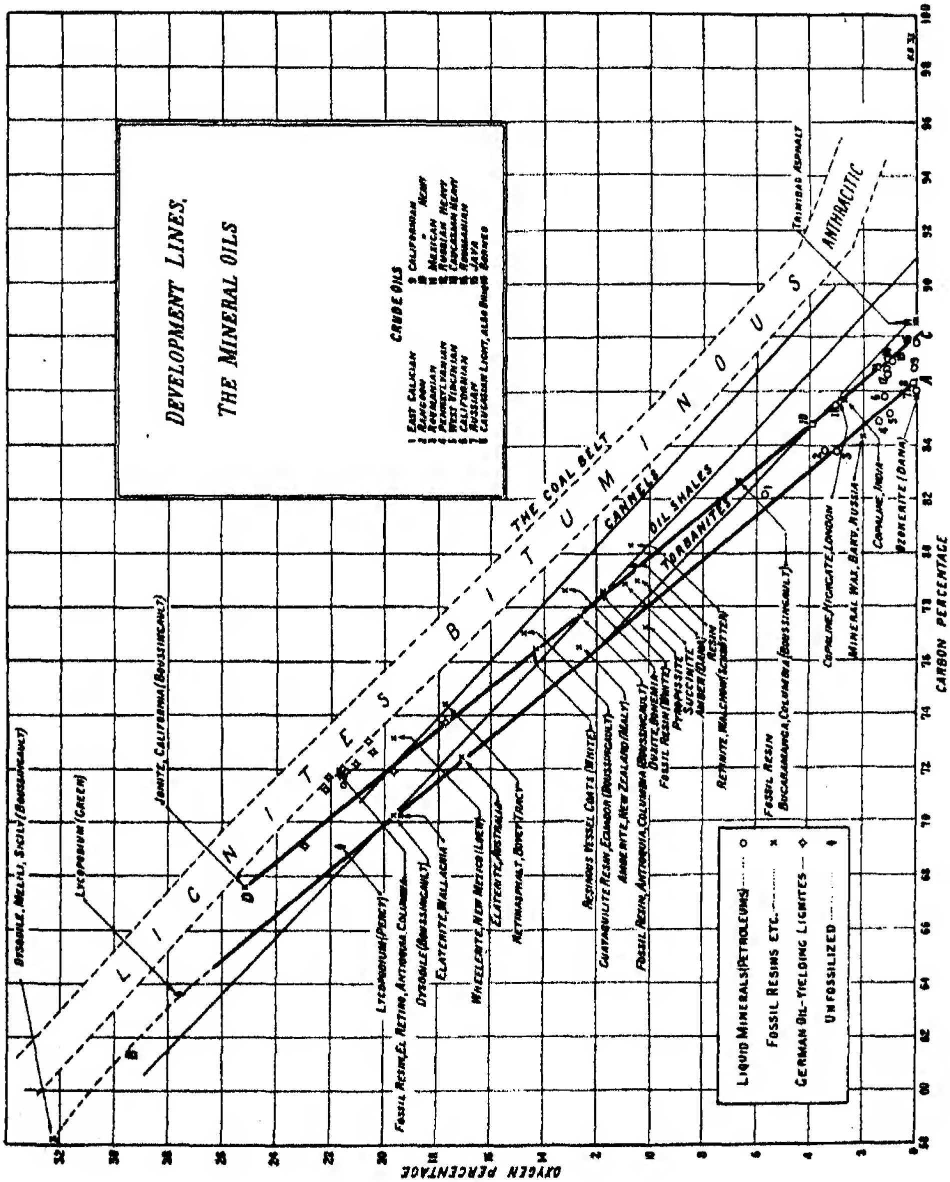
In order to make these disparate evolutionary courses clear, the development lines for the cannels, oil shales, and torbanites, copied from fig. 2 of the 1931 paper, have been drawn on the chart. The so-called "coal belt" is also shown. The analyses pertaining to the great family of the common coals, ranging from those of peat at the top left-hand to those of anthracite at the bottom right-hand corner, with very few exceptions, occupy positions on this narrow belt (Hickling, 1927). The coal belt is not straight, but its general course is similar in direction to those of the cannels, shale, and torbanites: all four lie at an angle of about 44 degrees to the abscissal (carbon) axis.

When the mineral resins and waxes were given their appropriate places on the chart, it was observed that their positions could not be connected by a line of this inclination, but that they lay more nearly on the lines *BA* and *DC*. In other words, these substances appear to belong to development lines whose high-rank products are the light and heavy crude oils, and whose end-products are ozokerite and a deoxygenated asphalt respectively. *BA* and *DC* are nearly parallel and their inclination to the carbon axis is about 50 degrees.

DC has been drawn straight; but an attentive examination of the places of the resins, from the low-rank jonite at the one extreme to the high-rank copalines at the other, suggests that their development line may be a flat curve, convex upwards.

Without reaching so far as actual proof, the chart suggests good presumptive evidence of the mineral oils having evolved through a solid phase in which they were closely kin to "fossil resins" in composition. Since the lines approach the coal belt more and more closely as they are followed

back (*i.e.* up) the chart until, with *DC* at least, there is an indication of merging with the belt at the stage of the more juvenile lignites, there is



more than a hint of the common origin of coal and oil. It would also seem not unlikely that the German oil-yielding lignites (for whose analyses I am indebted to Professor Frank of Berlin), which owe their special interest

and commercial value to the retinite they contain, are examples of fuels that, so to speak, have seceded from orthodoxy in their evolutionary course, and have chosen the route that will eventually change them, not to anthracite, but to oil.

This hypothesis of a progressive development of mineral oil through a resinoid phase is open to attack from three directions. In the first place, it may be objected that the resins of the chart are relatively scarce minerals —that they are not plentiful enough to be the forerunners of a substance that occurs so abundantly as oil. To this one may reply that, unlike coal, the main supply of oil comes from Tertiary deposits; that the chemical changes resulting in the production of oil from organic remains must be rapid in their action; and that with so speedy a transformation the products of intermediate rank are not necessarily to be found in bulk.

Secondly, it might be observed that copaline on the graph is in the midst of the oils; that the line *DC* shows that the trend of development of the resinoid minerals is towards copaline, but does not indicate that, late in the development process, the solid resins, etc. change into liquid oils. The rejoinder is that the development lines of the oils and the resin-like minerals are not likely to be identical by pure coincidence. Further, the slope of the lines *BA* and *DC*, being greater than 45 degrees, brings out the fact that the higher-rank minerals contain more hydrogen than those of lower rank; hence the tendency of these substances to liquefy increases with rank. And again, the mingling of solid and liquid substances of high rank is not a matter for surprise: ozokerite, generally accepted as a petroleum product, and, in fact, the end-product of the light-oil group, is a solid.

The third objection may be stated thus: The hypothesis requires that the resinoid minerals of the graph be regarded as so many milestones on the route to oil and as resulting from a prolonged chemical modification of plant tissue. But one of these minerals is amber, and the insects that are sometimes embedded in it prove it to have once been resin that flowed from the stems and branches of trees, just as resin exudes from them at the present time; therefore it cannot have been produced in the manner the theory postulates. The orthodox explanation of the origin of amber, however, may be accepted without prejudicing the position that that explanation would be invalid if applied to all the so-called "fossil resins," or, indeed, to all the minerals that pass as amber. That the resinoids were chiefly produced from lignite—despite the appearance of flies in amber—was effectively argued over eighty years ago by Bischof, and his conclusions are so much to the point that a few passages from his *Chemical and Physical Geology* (1854) may be quoted with advantage:

" The most dissimilar substances," he said, " may be produced from ligneous fibre, according to the nature of the change." Referring to amber, he continued: " Its occurrence disseminated throughout pitch coal and alternating with beds of bituminous wood as well as the fragments of brown coal and the bituminous earth associated with it, countenance the assumption that it has been formed from ligneous fibre, more especially as the pieces of wood found with the amber do not generally belong to the amber trees. . . . Retinite and asphalt, both so closely resembling amber, distinctly show that fossil resins may be formed by the decomposition of such [vegetable] remains. It is, therefore, very probable that amber is partly an educt and partly a product. . . ."

" In the decomposition of vegetable substances there are formed, besides carburetted hydrogen, liquid and solid hydrocarbons such as naphtha and petroleum or mineral oil, mineral tar, elaterite, naphthalite, ozokerite, etc."

Writing more than a decade earlier, Liebig (1842) expressed substantially the same view as Bischof as to the genesis of the resin-like minerals.

The chief purpose of this paper is to set forth the considerations leading me to the conclusions that coal and petroleum probably have a common origin in vegetable matter, and that their differences are the result of divergent courses of chemical evolution.

Obviously enough, the essential difference between the two descriptions of fuel lies in the percentage of hydrogen. If my main thesis be allowed, the course of development that leads to oil must have involved a gradual increase in the hydrogen percentage, while that that leads to anthracite, after preserving that percentage at an almost constant value, must eventually have permitted its decline. How have these variations arisen? To attempt an answer to that question is to carry the discussion into a new field, and, since both coal and oil call for consideration, it is advisable to deal with the matter in the separate paper which follows this.

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XII.—Products of the Natural Development of Coal and Oil.

By **Professor Henry Briggs,** D.Sc., Ph.D., University of Edinburgh. (With Two Text-figures.)

(MS. received January 12, 1934. Read June 4, 1934.)

Introduction.

THE discharge of gas from a coal seam or oil pool is at once the sign of a continuing change of composition in the fuel and an indication of the nature of the change. The process of change, which has been termed autometamorphism, is accelerated by warmth and pressure, and the chief by-products are carbon dioxide, methane, and water (Briggs, 1931). Other gases are found in fire-damp, but in proportions that are relatively so insignificant that, in the present connection, they may be altogether disregarded. The mixture known as "natural gas," occurring in association with petroleum, usually contains other hydrocarbons besides methane; indeed, the "wet" gas set free from oil when the natural pressure is released may consist almost entirely of members of the paraffin series heavier than methane. Nevertheless the natural gas obtained from oilfields is chiefly CH_4. The mean of 22 analyses of natural gas from oilfields in various parts of the world gives CH_4, 86·3; CO_2, 3·0; N_2, 6·2 per cent. (Bacon and Hamor, 1916). In a generalised inquiry, then, it will be sufficiently accurate to reckon the whole of the inflammable ingredient of both natural gas and fire-damp as methane.

The almost invariable occurrence of nitrogen in natural gas and fire-damp is a matter of much interest and its manner of production is well worthy of investigation; but as the *rank* or degree of maturing of a fuel depends only on the proportions of carbon, hydrogen, and oxygen it contains, the appearance of nitrogen in the gas emitted during the development process does not concern us here.

The part played by water in the reactions about to be considered is the most notable of any. At the peat and lignite stages of coalification the substance holds a large amount of absorbed water, and most of it is expressed as the operation proceeds. The expulsion of liquid water by physical means has no bearing on the matters that follow. Analyses being referred to the basis $C+H+O=100$ per cent., the discharge of water, to which frequent mention is made below, relates only to water

chemically produced. We shall, however, have need to discuss reactions in which water appears on the left-hand side of the equation, and in these instances some of the "free" water in the coal, or in contact with the oil, assumes an active rôle.

It is highly probable that an excess of water is associated with these fuels at all stages of their development. Owing to the relatively high solubility of CO_2 this water has a profound influence on the percentage of that product in fire-damp and natural gas; it alters the $CO_2 : CH_4$ ratio to the marked advantage of the latter compound. Thus the percentage of CO_2 in, say, a fire-damp can never be taken as representative of the relative production of the gas. For example, a lot of CO_2 is generated during the first stage of coalification—when fungi and aerobic bacteria cause the degradation of vegetable debris in a wet peat-bog; yet deceptively little carbon dioxide is discharged, as is indicated by the following volumetric analyses of samples of peat-gas:—

Peat-gas from Skye; analysed for the writer by T. Robertson, 1913: CH_4, 19·5; CO_2, 2·4; N_2, 78·1 per cent.

Peat-gas from Grunewald; analysed by Websky, 1864, cited by Percy: CH_4, 43·36; CO_2, 2·97; N_2, 53·67 per cent.

Commenting on the latter, Percy remarks: "As carbonic acid dissolves in water to a much greater extent than marsh-gas or nitrogen, it is not to be expected that an analysis of bubbles of gas evolved from a peat-bog would correctly indicate the true proportion of the gases produced" (Percy, 1875).

General Relations.

One hundred parts of a fuel of ultimate composition C', H', O' per cent. become 100 $(1-p)$ parts of higher-rank fuel of ultimate composition C'', H'', O'' per cent. by the discharge of x parts of water, y parts of methane, and z parts of carbon dioxide. Then

$$x+y+z=100p \qquad (1)$$

$$H'=100-C'-O'; \qquad H''=100-C''-O'' \qquad (2)$$

During the change the fuel loses $C'-(1-p)C''$ parts of carbon; $\frac{3}{4}$ of the weight of CH_4 produced and $\frac{3}{11}$ of that of CO_2 are carbon; therefore

$$\tfrac{3}{4}y+\tfrac{3}{11}z=C'-(1-p)C'' \qquad (3)$$

Similarly for hydrogen:

$$\frac{x}{9}+\frac{y}{4}=H'-(1-p)H'', \qquad (4)$$

and for oxygen:

$$\frac{8x}{9}+\frac{8z}{11}=O'-(1-p)O'' \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

The compositions C', H', O' and C'', H'', O'' are represented in the carbon-oxygen graph (fig. 1) by the points A and B respectively. These points lie on the development line of the particular fuel; the slope, a, of that line, and its intersection, D, with the carbon axis, are additional known factors that are available for substitution. The equation of the line is

$$C=-nO+C_0, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

where $n=\cot a$ and C_0 is as the figure denotes. The last four equations provide:

$$x=9\left[p\left(50-\frac{2C_0}{3}\right)-\left(\frac{7}{16}-\frac{2n}{3}\right)\left\{O'-(1-p)O''\right\}\right] \quad . \quad . \qquad (7)$$

$$y=2\left[p\left(100-\frac{2C_0}{3}\right)-\left(\frac{9}{8}-\frac{2n}{3}\right)\left\{O'-(1-p)O''\right\}\right] \quad . \quad . \qquad (8)$$

$$z=\frac{11}{2}\left[p\left(\frac{4C_0}{3}-100\right)+\left(\frac{9}{8}-\frac{4n}{3}\right)\left\{O'-(1-p)O''\right\}\right] \quad . \quad . \qquad (9)$$

These connect the production of water and gas with the characteristics of the development line, the loss in weight of the fuel, and the percentage of oxygen in the fuel at the beginning and end of the phase of development under consideration. The relationships have been stated in terms of the oxygen proportion, since, of the three elements, oxygen provides by far the clearest criterion of rank. Possessing four variables in x, y, z, and p, the three equations cannot be solved outright unless p, the reduction in weight, can be ascertained by other means—a matter receiving consideration below; but, as they stand, these equations furnish useful information as to the critical values of p. To elucidate the point, take the central part, KL, of the median line, JP, of the coal belt (fig. 2) (The belt is shown on the chart accompanying the preceding paper ("Graphical Classification of the Carbonaceous Minerals: The Mineral Oils") in these *Proceedings*.) Produced downwards, KL intersects the carbon axis at 94, and its slope is 45° 33′; hence $C_0=94$, $n=0{\cdot}981$; also

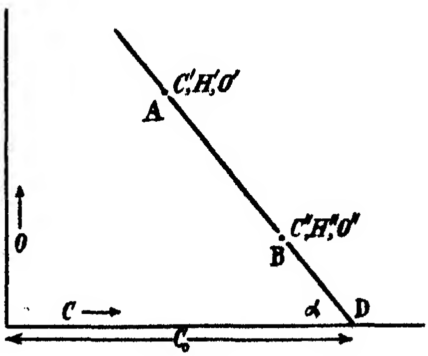

FIG. 1.

$O' = 24{\cdot}7$ and $O'' = 9{\cdot}2$. Equations (7), (8), and (9) now reduce to:

$$x = 9(3{\cdot}35 - 10{\cdot}71p) \quad . \quad . \quad . \quad . \quad . \quad (7\text{A})$$
$$y = 2(-7{\cdot}30 + 32{\cdot}97p) \quad . \quad . \quad . \quad . \quad (8\text{A})$$
$$z = \tfrac{11}{2}(-2{\cdot}84 + 23{\cdot}72p) \quad . \quad . \quad . \quad . \quad (9\text{A})$$

From (7A) it appears that x will be positive only if p is less than 0·31—that is to say, water will only be discharged during the phase in question if the shrinkage of the coal in weight is under 31 per cent. Similarly, (8A) provides that methane cannot be generated unless that shrinkage

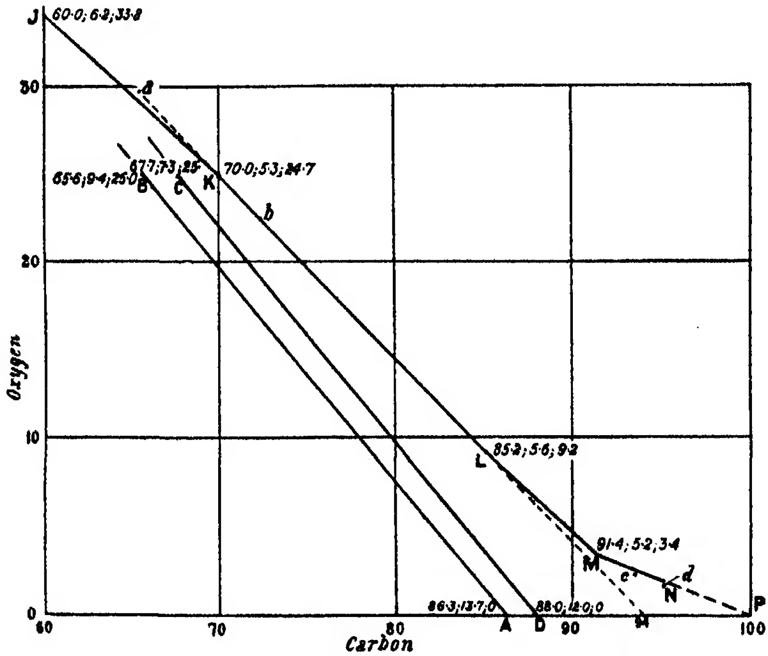

Fig. 2.

exceeds 22 per cent., while (9A) requires the loss in weight to be greater than 12 per cent. if CO_2 is to be a by-product of the change. If all three compounds are to be evolved, then the reduction in weight must lie between 22 and 31 per cent. Corresponding information in regard to the other phases of the peat-to-graphite transformation and to the oil development lines (fig. 2) is included in Table I. The lines BA and CD of fig. 2, namely, those pertaining to oil, are taken from the chart included with the preceding paper.

Some of the early writers on coal realised that the evolution of gas from seams proves that changes are proceeding in their composition, and Bischof and Law made simple calculations on the lines of equations (3),

TABLE I.—CRITICAL VALUES OF p, THE FRACTIONAL LOSS IN WEIGHT OF THE FUEL, FOR EACH PHASE OF DEVELOPMENT.

Phase.	Reference to Fig. 2.	C', H', O'.	C'', H'', O''.	If H_2O discharged.	If CH_4 discharged.	If CO_2 discharged.
1. *The Coal Belt.*						
Peat to lignite	JK	60·0; 6·2; 33·8	70·0; 5·3; 24·7	$p < 0{\cdot}35$	$p > 0{\cdot}14$	$p > 0{\cdot}15$
Lignite to bituminous	KL	70·0; 5·3; 24·7	85·2; 5·6; 9·2	$< 0{\cdot}31$	$> 0{\cdot}22$	$> 0{\cdot}12$
Bituminous to semi-bituminous	LM	85·2; 5·6; 9·2	91·4; 5·2; 3·4	$< 0{\cdot}12$	$> 0{\cdot}07$	$> 0{\cdot}07$
Semi-bituminous to graphite	MP	91·4; 5·2; 3·4	100; 0; 0	$< 0{\cdot}26$	$> -0{\cdot}06$ (*i.e.* CH_4 invariably evolved)	$> 0{\cdot}23$
2. *Mineral Waxes and Light Oils.*						
? to Ozokerite	BA	65·6; 9·4; 25·0	86·3; 13·7; 0	$p < 0{\cdot}35$	$p > 0{\cdot}34$	$p > -0{\cdot}07$ (*i.e.* CO_2 invariably evolved)
3. *Mineral Resins and Heavy Oils.*						
Jonite to de-oxygenated oil	CD	67·7; 7·3; 25·0	88·0; 12·0; 0	$p < 0{\cdot}29$	$p > 0{\cdot}35$	$p > -0{\cdot}06$ (*i.e.* CO_2 invariably evolved)

(4), and (5). They were hampered by scarcity of data, and their conclusions sometimes lack reliability; yet their almost forgotten labours deserve recognition.

Loss in Weight during Coalification.

Attempts have been made from time to time to estimate the amount of coal that would be formed from a given amount of raw vegetable matter or from a given amount of peat. Some of these are concerned with the total shrinkage involved—that is to say, they compare the thickness of the original peat-bog with that of the coal seam derived from it, and generally reach the conclusion that the seam is somewhere between one-twentieth to one-thirtieth as thick as the parent bog. As the bog would consist of considerably more water than solid matter, and as its liquid content does not enter into these calculations, an ascertainment of that kind is of little or no use at the moment. Much more to the point, however, is an estimate quoted by W. E. Appleby (1921); it relates to the solid substance only, and is to the effect that 100 lb. of "ligneous material" is capable of yielding 60 lb. of peat, and, in course of time, 40 lb. of lignite, 25 lb. of bituminous coal, and 15 lb. of graphite. Whatever may have been the basis of computation, Appleby's figures provide, I find, a serviceable standard of comparison. Omitting the first stage, they may be restated thus:

Peat to lignite	$p = 0{\cdot}33$
Lignite to bituminous coal . .	$p = 0{\cdot}38$
Bituminous coal to graphite . .	$p = 0{\cdot}40$
Peat to graphite	$p = 0{\cdot}75$

Professor W. A. Bone published (1921 and 1923) accounts of experiments bearing on the artificial maturing of lignites, and one of his results is useful in evaluating p over the lignite phase. He heated several lignites to different temperatures, measured and analysed the gases discharged, and determined the weight and composition of the solid residues. I propose to make use of the results of one of these tests only, namely, that in which lignite from Morwell, Victoria, Australia, was heated to 375° C. Though such a treatment obviously differs a great deal from that involved in the slow, natural passage of a low-rank lignite into one of higher rank, the compounds evolved are very similar. Those driven off during the heating were, almost entirely, water and carbon dioxide, methane being absent. (The relative rarity of CH_4 and the abundance of CO_2 are matters of regular observation in the gases emitted underground from lignite.) Moreover, the composition of the residue left

after heating, when translated to the $C+H+O=100$ basis, furnishes on the graph (fig. 2) a point *b* that lies almost exactly on the coal median. Unfortunately other lignites—and the Morwell lignite itself heated to higher temperatures—do not yield information of the same serviceableness; the gases they evolved contained too large an amount of compounds that find no place among those discharged underground, and the analyses of the solid residues, when referred to the chart, are too wide of the coal belt to be worthy of consideration in the present connection.

Raised to 375° C. the Morwell lignite (previously dried) emitted 1270 cub. ft. (at N.T.P.) of gas per ton; of this volume carbon dioxide accounted for no less than 1180 cub. ft. The loss in weight, in fact, was nearly all due to the expulsion of 145·5 lb. of CO_2 and 122·6 lb. of water per ton. In addition, the test furnished the following particulars:—

TABLE II.—ARTIFICIAL MATURING OF MORWELL LIGNITE RECALCULATED FROM BONE'S DATA.

	Morwell Lignite ("pure coal" basis).	Heated to 375° C.
Fractional loss in weight (p)	..	0·13
		Residue.
C	65·5	72·4
H	5·1	5·2
O	29·4	22·4
	100·0	100·0
Position on fig. 2 .	*a*	*b*

The knowledge that no methane is formed during the evolution of a lignite from *a* to *b* (fig. 2) makes it a simple matter to check by calculation the observed fractional loss (0·13) entered in the table. Referring back to equations (7), (8), and (9), y has now to be equated to zero; and substituting $C_0=94$, $n=0·98$, $O'=29·4$, and $O''=22·4$, the remaining factors are ascertained to be:

$p=0·12$.
x (water discharged) $=4·90$ per cent.
z (CO_2 discharged) $=7·48$ per cent.

In comparison with these, Bone's experimental results credited the change with a rather greater production of water and a correspondingly smaller production of CO_2; yet the two values of p are in reasonably close agreement.

There being a kink in the coal line at K (C, 70·0; O, 24·7), that point

becomes a natural division between the peats and less mature lignites positioned on or near JK and the more mature lignites and bituminous coals ranged on or near KL. Table II indicates that lignite *a* loses 0·13 of its weight in becoming lignite *b*; its loss in becoming lignite K is therefore about 0·09. The point *a* happens to lie on a continuation of the line LK. If the development of the coal from K to L were in a chemical sense also a continuation of the development from *a* to K—in other words, if nothing except water and CO_2 were expelled in the phase KL—the solution of the appropriate equations determines that 100 parts of coal of composition K would become 78 parts of composition L ($p = 0{\cdot}22$). Near the beginning of the phase—during the part Kb, for example—underground observation indicates a general absence of CH_4, but towards its end fire-damp consisting chiefly of CH_4 is emitted from the coal. The last column but one of Table I states that, for the range KL, p must exceed 0·22 if CH_4 is to be generated. So far as KL is concerned, then, it is certain that both CO_2 and CH_4 are discharged, and very probable that water is emitted also; p must lie somewhere between 0·22 and 0·31, and probably $p = 0{\cdot}27$ will not be far from the truth. Substituting that value in equations (7A), (8A), and (9A), we find that, when changing from K to L, the coal discharges 4·1 of water, 3·2 of methane, and 19·6 per cent. of carbon dioxide.

Let us now attempt a similar estimation for the peat-to-lignite phase, JK (fig. 2). Bone's test has already provided a result (0·09) for the loss in weight involved in the change from *a* to K—a change (so we have seen) that yields CO_2 and water and no methane. The composition of the material at J is very nearly the average for peat. At first decomposition of the peat would proceed by aid of aerobic organisms in the higher parts of the bog and of anaerobic bacteria in the deeper parts. Somewhere between J and *a* (fig. 2) the deposit was covered by sediments; its access to air was gradually cut off; the aerobic organisms disappeared, but anaerobic action continued for a time in the buried mass (White, 1913).

As Liebig (1842) observed, the putrefaction of woody matter in the presence of water and absence of air requires the consumption of water. It may be added that, under bacterial action in general, the loss of weight proceeds at a rapid rate, and that p cannot be other than high if water is absorbed in the process. Table I, in fact, indicates that if water were taken up during the whole of phase JK and both CH_4 and CO_2 were discharged, p must exceed 0·35. We know that that reaction did not continue so long, for in changing from *a* (or thereabouts) to K the coal discharged water and CO_2; we have also seen that, near J, before the bog was covered by later deposits, CO_2, CH_4, and water were all expelled.

Not to exaggerate the effect of the anaerobic or water-abstracting episode it seems reasonable to allow, for the phase J*a*—itself about half the phase JK—a little more than one-half the critical value (0·35) of Table I, and I suggest 0·20 as a suitable estimate. If, then, the substance J lost 20 per cent. in changing to *a*, and *a* a further 9 per cent. in changing to K, the loss in weight over the range JK was 27 per cent. ($p=0·27$). Appleby's figure relating to the conversion of peat to lignite (*vide supra*) is 6 per cent. higher than this.

Substituting $p=0·27$, $C_0=97·1$, $n=1·10$, $O'=33·8$, and $O''=24·7$ in equations (7), (8), and (9) we find that, during the phase JK 14·6 per cent. of the weight of the peat is lost as CO_2, 6·6 per cent. as CH_4, and 5·8 per cent. as water. To all appearances, then, the types of reaction producing water and operating at the beginning and end of the phase outweigh the reaction consuming water that had its season sometime during the first half of the stage.

Turning to the phase LM (fig. 2) we gather from Table I that, if all three major by-products are to be produced, p must lie between 0·12 and 0·07. As there is no reason to doubt the generation of any of the three, and as the range of p is small, it appears suitable to select the mean value or 0·09—that is to say, 100 parts of coal L yields about 91 parts of coal M, and the change is effected by the discharge of 4·3 of water, 1·6 of methane, and 3·1 parts by weight of carbon dioxide.

The last and most interesting stage of the development process is represented by MNP (fig. 2), and concerns the passage of a semi-bituminous coal, M, to anthracite of 95 per cent. carbon, N, and then to pure graphite, P.

The manner of formation of anthracite from coal of lower rank has commanded attention for many years; and though opinion of late has hardened in the direction of allowing that pressure generally plays the chief part in the metamorphosis, it has to be granted that the process cannot always have been the same in all areas. In the South Wales and Pennsylvanian coalfields, which are remarkably free from igneous intrusions, thrust pressure has, almost certainly, been the prime agent (White, 1913; Briggs, 1923). In Scotland, on the other hand, anthracite is never found except in the neighbourhood of dolerite sills or lateral intrusions, and it is usually assumed that the heat of these masses was the effective cause. Certainly the evidence that heat had something to do with the change is, in these latter instances, too strong to be set aside; yet where the heating of coal *in situ* is most considerable—namely, when the seam is crossed by a dyke—the coal is converted to coke and not to anthracite, and the effect is highly localised. The intrusion of sills totalling about

300 feet in thickness, as in the Stirling district (Geological Survey Memoir, 1932), must have given rise to considerable pressure, so that pressure probably shared with warmth the responsibility for the alteration in the composition of the Scottish seams. As I hope to show, another factor completely overlooked by all recent workers on the subject—namely, water —is required during this final phase. The following numbered paragraphs set out the evidence favouring this view.

1. On a broad question of this kind the older authorities are frequently the best informed. The following is an extract from Prestwich's *Geology*, 1886: "While it requires a red heat to convert coal into coke, its conversion into anthracite is effected in presence of moisture at much lower temperatures. . . . M. Daubrée has even converted wood, by exposure for some time in water under pressure to a temperature of 300° C. (572° Fahr.), into an anthracite so hard as scarcely to be touched by steel, and so infusible as to burn with extreme slowness even in the oxidising flame of the blowpipe." Intrusions of great bulk always expel steam as they cool, so that there is no difficulty in accounting for the water in connection with such occurrences of anthracite as those of Stirlingshire.

2. Analyses of fire-damp discharged underground from semi-bituminous coal and anthracite show it to contain carbon dioxide as well as methane (Graham and Shaw, 1927). Table I states that CH_4 is invariably discharged during the phase MP (fig. 2), no matter what be the weight lost in the process, and that the condition for the generation of CO_2 is for p to exceed 0·23. If p happen to be between 0·23 and 0·26—limits that are exceptionally close—water will also be evolved; but if p should exceed 0·26, the reactions can only take place if water is consumed.

3. Appleby's estimate of p for the stage bituminous coal to graphite is 0·40. Even if we concede that that stage may extend all the way from L to P and not merely from M to P, and if we make a correction ($p=0·09$) for LM, the value of p for the phase MP works out at 0·34—a value requiring a considerable consumption of water if it is to be realised.

4. It has been noticed in South Wales that when a seam is traced in a westerly direction it loses volatile matter and generally decreases in thickness. By way of exemplifying these variations in dimensions Jordan (1910) refers to the Nine Feet seam, which is 9 feet thick in the Aberdare district, where it is a steam coal of average "pure coal" composition *C*, 93·5; *H*, 4·3; *O*, 2·2 per cent., and which becomes 5 feet 6 inches in thickness in the Amman valley, where it is an anthracite having an average composition of *C*, 95·1; *H*, 3·3; *O*, 1·6 per cent. The steam coal takes the position *c* on the graph (fig. 2) and the anthracite the position *d*. Making an allowance of 6 inches to compensate for the

reduction in thickness of the dirt bands that are present in the steam coal and absent in the anthracite, and for the small increase of density that accompanies the change, the example furnishes a value for p of 0·35 over the relatively small range *cd*. This denotes a much more rapid rate of loss of weight than Appleby allowed. Obviously enough an estimate of p based on such measurements as these is precarious, since there are other reasons for the thinning of a seam besides that of changing composition; nevertheless, Jordan's comparison gives support (however slight) to the view that the loss of substance during the phase MP is considerable—that, indeed, it is of such magnitude as to make the consumption of water necessary if the chemical equations are to be satisfied.

5. The sharp change in direction at M is the most striking feature of the coal development line. As development lines are nothing else than the graphical expression of the consequences of chemical action, a swerve in the line must indicate a change in that action, and clearly the change at M must be profound. As we have seen, the process of evolution of the coal during much of *b*L and the whole of LM involves the discharge of CH_4, CO_2 and water. The two gases continue to be emitted during the phase MP. Thus the alteration at M is almost certainly concerned with the third of these compounds. Being so limited, the magnitude of the effect suggests that water is consumed instead of expelled.

The trend of the evidence thus supports Prestwich's conclusion. In view of these considerations I propose to take 0·4 as a likely value of p for the final phase. Introducing that value into equations (7), (8), and (9), it appears that 100 parts of coal M will become 60 parts of pure graphite P by taking up 22·0 parts of water and expelling 30·6 of CH_4 and 31·4 of CO_2 by weight. Similarly, 100 parts of coal M will yield about 83 of anthracite N (95·0; 3·6; 1·4) by consuming 9·2 of water and giving up 12·8 of CH_4 and 13·2 of CO_2.

Table III summarises the results so far obtained in regard to the development or natural evolution of graphite from a peat of average composition. The estimated proportion of graphite—namely, 29 per cent. of the weight of the peat—is 4 per cent. higher than the corresponding figure given by Appleby. Seemingly nearly as much water is consumed during the last two stages of the process as is discharged during the first three. Of the two gaseous products carbon dioxide is produced in greater amount, by weight, at all stages, though methane becomes more important in the concluding phases. By volume, 1·2 times as much CH_4 as CO_2 is emitted over the range peat to anthracite, and 1·5 times as much over the range peat to graphite.

TABLE III.—APPROXIMATE RESULTS OF THE NATURAL TRANSFORMATION OF PEAT TO GRAPHITE.

Rank.	Weight of Fuel derived from 100 Parts of Peat.	Products Expelled during each Phase (parts by weight).			Total Products Expelled (parts by weight).		
		H_2O.	CH_4.	CO_2.	H_2O.	CH_4.	CO_2.
Peat	100	..	..	..	..	..	..
(*C*, 60·0; *H*, 6·2; *O*, 33·8)	..	6	6·5	14·5	..	..	..
Lignite	73	..	..	..	6	6·5	14·5
(70·0; 5·3; 24·7)	..	3	2·5	14·5	..	..	..
Bituminous coal	53	..	..	..	9	9	29
(85·2; 5·6; 9·2)	..	2·5	1	1·5	..	..	..
Semi-bituminous coal	48	..	..	..	11·5	10	30·5
(91·4; 5·2; 3·4)	..	−4·5	6	6·5	..	..	..
Anthracite	40	..	..	..	7	16	37
(95·0; 3·6; 1·4)	..	−6·5	8·5	9	..	..	..
Graphite	29	..	..	..	0·5	24·5	46
(100; 0; 0)							

DEVELOPMENT OF THE MINERAL OILS.

The preceding paper in these *Proceedings* discussed the evidence favouring the view that the evolution of the heavy and light petroleums is graphically represented by the lines CD and BA respectively. Table I of the present communication provides the information that, during the change denoted by DC, CO_2 must invariably be emitted, no matter what the value of p, the fractional loss of weight, may be. It also lays down the conditions that p must be less than 0·29 if water is to be expelled and greater than 0·35 if CH_4 is to be given up. Since it is impossible to fulfil both the conditions at the same time, it is clear that one of the two products cannot be produced. We have, however, seen that CH_4 is the chief constituent of the "natural gas" of oilfields. So far as the heavy oils are concerned then, we discover that p must exceed 0·35 and that water cannot be one of the by-products of the natural process of generation. By introducing $p=0{\cdot}35$ (or anything exceeding that figure) and the appropriate values of C_0 and n in equation (7) and solving for x, a negative value is obtained; in other words, the transformation from C to D involves the consumption of water.

With the light oil line, BA, water is discharged if p is less than 0·35 and CH_4 if p exceeds 0·34. Both would therefore be emitted during the change from B to A if p were, say, 0·345; yet for so extensive a change such a value is almost certainly too small, and there seems no reason

to doubt that the conclusion as to the absorption of water—which cannot be avoided with CD—applies to BA also.

An indication of the magnitude of p, the fractional loss of weight experienced by a substance of the rank of lignite in undergoing transformation into oil, is afforded by the Saxon retinite-lignites (average "pure coal" composition: C, 72; H, 7; O, 21 per cent.), which, on retorting, yield an average of 50 gallons of crude oil per ton of "pure coal," or about 20 per cent. by weight ($p=0{\cdot}8$). Retorting and natural evolution are, of course, not comparable processes; but even when a wide allowance is made to cover the discrepancy—for example, if p under natural conditions is taken as 0·4, or one-half the stated value—the change is chemically feasible only when a considerable proportion of water is taken up. If the change represented by CD (fig. 2) were effected with a loss of 0·6 of the weight of substance at C, that loss would be the balance between 20 per cent. of methane and 63 per cent. of carbon dioxide expelled, and 23 per cent. of water consumed.

Conclusion.

As was shown in the preceding paper, the development lines indicate that coal and petroleum were probably derived from raw materials of a peat-like character that were chemically very similar if not identical, and that the products as now found are the results of different evolutionary processes. The present paper discusses the nature of the difference, and leads to the general conclusion that, whereas coal up to the semi-bituminous rank is produced by a chemical process or series of processes that expels carbon dioxide, methane, and water, petroleum is the outcome of a process that expels the same two gases but requires the consumption of water.

At an early and relatively unimportant stage of the course that leads to coal (namely, in the vicinity of J, fig. 2) it appears likely that water is taken up; and during the final and much more important phase, MNP, in which semi-bituminous coal is changed to anthracite and then to graphite, water is required on the left-hand side of the chemical equation as a condition necessary for the solution of that equation. On the other hand, the natural generation of oil involves the consumption of water during the whole evolutionary range depicted by fig. 2. It may be presumed that pressure and warmth assist the reactions.

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XIII.—Some Integrals, with respect to their Degrees, of Associated Legendre Functions. By Professor T. M. MacRobert, M.A., D.Sc., University of Glasgow.

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§ 1. *Introductory.* — Little is known regarding the integration of Legendre Functions with respect to their degrees. In this paper several such integrals are evaluated, three different methods being employed. In § 2 proofs are given of a number of formulæ which are required later. In § 3 an example is given of the evaluation of an integral by contour integration. The following section contains the proof of a formula of the Fourier Integral type, a special case of which was given in a previous paper (*Proc. Roy. Soc. Edin.*, vol. li, 1931, p. 123). In § 5 an integral is evaluated by employing Fourier's Integral Theorem; while in § 6 other integrals are evaluated by means of expansions in series.

§ 2. *Preliminary Formulæ.*—The Associated Legendre Function of the First Kind of degree $\lambda-\frac{1}{2}$ and order $-\mu$ can be defined by the equation

$$T_{\lambda-\frac{1}{2}}^{-\mu}(x)=\frac{1}{\Gamma(\mu+1)}\left(\frac{1-x}{1+x}\right)^{\frac{1}{2}\mu}F\left(\tfrac{1}{2}-\lambda,\ \tfrac{1}{2}+\lambda;\ \mu+1;\ \frac{1-x}{2}\right) \quad . \quad \text{(i)}$$

in a form which gives real values for the function when $-1<x<1$ and λ and μ are real. It is advantageous to employ the notation

$$T(\lambda,\mu,\theta)=T_{\lambda-\frac{1}{2}}^{\mu}(\cos\theta), \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

and to write $E(x)$ for $\exp(x)$. As some of the formulæ are rather cumbersome this notation has been adopted in order to make them more compact. From (ii) it follows that

$$T(\lambda,\mu,\pi-\theta)=T_{\lambda-\frac{1}{2}}^{\mu}(-\cos\theta). \quad . \quad . \quad . \quad \text{(iii)}$$

The formula which gives the values of these functions when λ is large may now be written

$$T(\lambda,\mu,\theta)=\frac{1}{\sqrt{(2\pi\sin\theta)}}\frac{\Gamma(\lambda+\mu+\frac{1}{2})}{\Gamma(\lambda+1)}$$
$$\times[E\{-\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i-i\lambda\theta\}P(\lambda,\mu,-\theta)+E\{\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i+i\lambda\theta\}P(\lambda,\mu,\theta)], \quad \text{(iv)}$$

where $0<\theta<\pi$ and

$$P(\lambda,\mu,\theta)=F\left(\tfrac{1}{2}+\mu,\ \tfrac{1}{2}-\mu;\ \lambda+1;\ \frac{e^{i\theta}}{2i\sin\theta}\right). \quad . \quad . \quad \text{(v)}$$

The function $T(\lambda, \mu, \theta)$ is even in λ, while $P(\lambda, \mu, \theta)$ is even in μ and has a period π in θ. For further information regarding these formulæ reference may be made to the author's *Complex Variable* (Second Edition), Appendix III.

In (iv) replace θ by $\pi-\theta$; then

$$T(\lambda, \mu, \pi-\theta)=\frac{1}{\sqrt{(2\pi\sin\theta)}}\frac{\Gamma(\lambda+\mu+\frac{1}{2})}{\Gamma(\lambda+1)}$$
$$\times[E\{-\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i-i\lambda(\pi-\theta)\}P(\lambda,\mu,\theta)+E\{\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i+i\lambda(\pi-\theta)\}P(\lambda,\mu,-\theta)], \quad \text{(vi)}$$

where $0<\theta<\pi$.

Now eliminate $P(\lambda, \mu, -\theta)$ between (iv) and (vi), and get

$$\frac{1}{\sqrt{(2\pi\sin\theta)}}\frac{\Gamma(\lambda+\mu+\frac{1}{2})}{\Gamma(\lambda+1)}2i\cos(\lambda+\mu)\pi E(i\lambda\theta)P(\lambda,\mu,\theta)$$
$$=E\{-\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i\}T(\lambda,\mu,\pi-\theta)-E\{i\lambda\pi+\tfrac{1}{2}(\mu-\tfrac{1}{2})\pi i\}T(\lambda,\mu,\theta). \quad \text{(vii)}$$

If $\lambda+\mu-\frac{1}{2}=p$, where p is zero or a positive integer, it follows that

$$T^{\mu}_{\lambda-\frac{1}{2}}(-\cos\theta)=(-1)^p T^{\mu}_{\lambda-\frac{1}{2}}(\cos\theta). \quad . \quad . \quad . \quad \text{(viii)}$$

In (vii) replace λ and μ by $-\lambda$ and $-\mu$; then, noting that $P(-\lambda,-\mu,\theta)=P(-\lambda,\mu,\theta)$ and $T(-\lambda,\mu,\theta)=T(\lambda,\mu,\theta)$, we have

$$\frac{1}{\sqrt{(2\pi\sin\theta)}}\frac{\Gamma(\lambda)}{\Gamma(\lambda+\mu+\frac{1}{2})}2i\sin\lambda\pi E(-i\lambda\theta)P(-\lambda,\mu,\theta)$$
$$=E\{\tfrac{1}{2}(\mu+\tfrac{1}{2})\pi i\}T(\lambda,-\mu,\pi-\theta)-E\{-i\lambda\pi-\tfrac{1}{2}(\mu+\tfrac{1}{2})\pi i\}T(\lambda,-\mu,\theta). \quad \text{(ix)}$$

If we substitute from (iv) and (vi) in the *R.H.S.* of (ix), and multiply by $\sqrt{(2\pi\sin\theta)}$, it becomes

$$\frac{\Gamma(\lambda-\mu+\frac{1}{2})}{\Gamma(\lambda+1)}\left[\begin{array}{l}E\{(\mu+\frac{1}{2})\pi i-i\lambda(\pi-\theta)\}P(\lambda,\mu,\theta)+E\{i\lambda(\pi-\theta)\}P(\lambda,\mu,-\theta)\\ -E\{-i\lambda(\pi+\theta)\}P(\lambda,\mu,-\theta)-E\{-(\mu+\frac{1}{2})\pi i-i\lambda(\pi-\theta)\}P(\lambda,\mu,\theta)\end{array}\right],$$

so that

$$\sin\lambda\pi P(-\lambda,\mu,\theta)=\frac{\Gamma(\lambda+\mu+\frac{1}{2})\Gamma(\lambda-\mu+\frac{1}{2})}{\Gamma(\lambda)\Gamma(\lambda+1)}$$
$$\times\{\cos\mu\pi E(2i\lambda\theta-i\lambda\pi)P(\lambda,\mu,\theta)+\sin\lambda\pi P(\lambda,\mu,-\theta)\}. \quad \text{(x)}$$

Thus the residue of $P(-\lambda,\mu,\theta)$ at $\lambda=n$, where $n=1, 2, 3, \ldots$, is

$$\frac{\Gamma(n+\mu+\frac{1}{2})\Gamma(n-\mu+\frac{1}{2})}{\Gamma(n)\Gamma(n+1)}\cdot\frac{\cos\mu\pi}{\pi}E(2in\theta)P(n,\mu,\theta), \quad . \quad . \quad \text{(xi)}$$

while the residue of $P(\lambda,\mu,\theta)$ at $\lambda=-n$ is equal to this in value but opposite in sign.

Again, from (vii) and (ix) we have

$$2\sin\lambda\pi\cos(\lambda+\mu)\pi E\{i\lambda(\theta-\phi)\}P(\lambda,\mu,\theta)P(-\lambda,\mu,\phi)=\lambda\pi\sqrt{(\sin\theta\sin\phi)}$$

$$\times\begin{bmatrix}\cos(\lambda+\mu)\pi\{T(\lambda,\mu,\theta)T(\lambda,-\mu,\pi-\phi)+T(\lambda,\mu,\pi-\theta)T(\lambda,-\mu,\phi)\}\\ +i\sin(\lambda+\mu)\pi\{T(\lambda,\mu,\theta)T(\lambda,-\mu,\pi-\phi)-T(\lambda,\mu,\pi-\theta)T(\lambda,-\mu,\phi)\}\\ +iT(\lambda,\mu,\theta)T(\lambda,-\mu,\phi)-iT(\lambda,\mu,\pi-\theta)T(\lambda,-\mu,\pi-\phi)\end{bmatrix}. \quad \text{(xii)}$$

Similarly

$$2\sin\lambda\pi\cos(\lambda+\mu)\pi\begin{bmatrix}E\{i\lambda(\phi-\theta-\pi)\}P(-\lambda,\mu,\theta)P(\lambda,\mu,\phi)\\ -E\{-i\lambda(\phi-\theta-\pi)\}P(\lambda,\mu,\theta)P(-\lambda,\mu,\phi)\end{bmatrix}=\lambda\pi\sqrt{(\sin\theta\sin\phi)}$$

$$\times\begin{bmatrix}iE(-i\lambda\pi)T(\lambda,-\mu,\theta)T(\lambda,\mu,\phi)-iE(i\lambda\pi)T(\lambda,\mu,\theta)T(\lambda,-\mu,\phi)\\ -iE(-i\lambda\pi)T(\lambda,-\mu,\pi-\theta)T(\lambda,\mu,\pi-\phi)+iE(i\lambda\pi)T(\lambda,\mu,\pi-\theta)T(\lambda,-\mu,\pi-\phi)\\ +E(i\mu\pi)T(\lambda,-\mu,\pi-\theta)T(\lambda,\mu,\phi)-E(-i\mu\pi)T(\lambda,\mu,\pi-\theta)T(\lambda,-\mu,\phi)\\ +E\{-i(2\lambda+\mu)\pi\}T(\lambda,-\mu,\theta)T(\lambda,\mu,\pi-\phi)\\ \qquad -E\{i(2\lambda+\mu)\pi\}T(\lambda,\mu,\theta)T(\lambda,-\mu,\pi-\phi)\end{bmatrix}. \quad \text{(xiii)}$$

Finally, if m is an integer

$$\Gamma(\lambda+m+\tfrac{1}{2})T^{-m}_{\lambda-\frac{1}{2}}(x)=(-1)^m\Gamma(\lambda-m+\tfrac{1}{2})T^{m}_{\lambda-\frac{1}{2}}(x), \quad \text{(xiv)}$$

and therefore

$$T(\lambda,m,\theta)T(\lambda,-m,\phi)=T(\lambda,-m,\theta)T(\lambda,m,\phi). \quad \text{(xv)}$$

§ 3. *Evaluation of an Integral by Contour Integration.*—Consider the integral of

$$\frac{E(2i\pi\zeta)}{2i\pi\zeta}[E\{i\zeta(\theta-\phi)\}P(\zeta,\mu,\theta)P(-\zeta,\mu,\phi)+E\{-i\zeta(\theta-\phi)\}P(-\zeta,\mu,\theta)P(\zeta,\mu,\phi)],$$

taken round a contour which consists of the real axis from $-p-\frac{1}{2}$ to $p+\frac{1}{2}$ (p a positive integer), indented by small semicircles above the ξ-axis at $0, \pm 1, \pm 2, \ldots, \pm p$, and that half of the circle $|\zeta|=p+\frac{1}{2}$ which lies above the ξ-axis. To begin with it may be assumed that θ and ϕ lie in the open interval $(\frac{1}{6}\pi, \frac{5}{6}\pi)$, so that the series for the P's are convergent for non-integral values of ζ. Then, when $p\to\infty$, the integral round the large semicircle tends to zero; and, since the integrand is holomorphic within the contour,

$$\int_0^\infty \frac{\sin 2\pi\xi}{\pi\xi}[E\{i\xi(\theta-\phi)\}P(\xi,\mu,\theta)P(-\xi,\mu,\phi)+E\{-i\xi(\theta-\phi)\}P(-\xi,\mu,\theta)P(\xi,\mu,\phi)]d\xi$$

$=i\pi\times$ the sum of the residues at $0, \pm 1, \pm 2, \ldots$

On referring to (xii) and equating real parts we see that

$$\int_0^\infty \cos\lambda\pi\begin{Bmatrix}T^\mu_{\lambda-\frac{1}{2}}(\cos\theta)T^{-\mu}_{\lambda-\frac{1}{2}}(-\cos\phi)+T^\mu_{\lambda-\frac{1}{2}}(-\cos\theta)T^{-\mu}_{\lambda-\frac{1}{2}}(\cos\phi)\\ +T^\mu_{\lambda-\frac{1}{2}}(\cos\phi)T^{-\mu}_{\lambda-\frac{1}{2}}(-\cos\theta)+T^\mu_{\lambda-\frac{1}{2}}(-\cos\phi)T^{-\mu}_{\lambda-\frac{1}{2}}(\cos\theta)\end{Bmatrix}d\lambda$$

$$=\tfrac{1}{2}\sum_{n=-\infty}^{\infty}(-1)^n\begin{Bmatrix}T^\mu_{n-\frac{1}{2}}(\cos\theta)T^{-\mu}_{n-\frac{1}{2}}(-\cos\phi)+T^\mu_{n-\frac{1}{2}}(-\cos\theta)T^{-\mu}_{n-\frac{1}{2}}(\cos\phi)\\ +T^\mu_{n-\frac{1}{2}}(\cos\phi)T^{-\mu}_{n-\frac{1}{2}}(-\cos\theta)+T^\mu_{n-\frac{1}{2}}(-\cos\phi)T^{-\mu}_{n-\frac{1}{2}}(\cos\theta)\end{Bmatrix}. \quad \text{(xvi)}$$

If $0<\theta\leq\frac{1}{6}\pi$ or $\frac{5}{6}\pi\leq\theta<\pi$ the series $P(\zeta,\mu,\theta)$ is asymptotic in ζ for $0\leq\text{amp}\,\zeta\leq\frac{1}{2}\pi$ (*Proc. Edin. Math. Soc.*, vol. xlii, 1923, p. 84). If

$\frac{1}{2}\pi <$ amp $\zeta \leqq \pi$ the asymptotic expansion is given by (x). Thus the integral round the large semicircle tends to zero for values of θ and ϕ outside as well as inside the range $(\frac{1}{8}\pi, \frac{5}{8}\pi)$. On the remaining parts of the contour the integrand can then be expressed in valid form by means of (xii). Hence (xvi) holds for $0<\theta<\pi$, $0<\phi<\pi$.

If $\phi=\pi-\theta$, (xvi) becomes

$$\int_0^\infty \cos\lambda\pi\{T^\mu_{\lambda-\frac{1}{2}}(\cos\theta)T^{-\mu}_{\lambda-\frac{1}{2}}(\cos\theta)+T^\mu_{\lambda-\frac{1}{2}}(-\cos\theta)T^{-\mu}_{\lambda-\frac{1}{2}}(-\cos\theta)\}d\lambda$$

$$=\frac{1}{2}\sum_{n=-\infty}^{\infty}(-1)^n\{T^\mu_{n-\frac{1}{2}}(\cos\theta)T^{-\mu}_{n-\frac{1}{2}}(\cos\theta)+T^\mu_{n-\frac{1}{2}}(-\cos\theta)T^{-\mu}_{n-\frac{1}{2}}(-\cos\theta)\}, \quad \text{(xvii)}$$

where $0<\theta<\pi$.

If imaginary parts are equated, and the resulting equation, when m is integral, simplified by means of (xv), it becomes

$$\int_0^\infty \{T(\lambda, m, \theta)T(\lambda, -m, \phi)-T(\lambda, m, \pi-\theta)T(\lambda, -m, \pi-\phi)\}d\lambda$$

$$=\frac{1}{2}\sum_{n=-\infty}^{\infty}\{T(n, m, \theta)T(n, -m, \phi)-T(n, m, \pi-\theta)T(n, -m, \pi-\phi)\},$$

where $0<\theta<\pi$, $0<\phi<\pi$.

It will now be shown that the *R.H.S.* of this equation has the value zero. Consider the integral of

$$T^{-\kappa}_\zeta(\cos\theta)T^{-\mu}_\zeta(\cos\phi)\frac{1}{\sin\pi(\zeta-\alpha)\sin\pi(\zeta-\beta)},$$

where $0<\theta<\pi$, $0<\phi<\pi$, $\kappa+\mu>-1$, taken round a circle $|\zeta|=p+\gamma$, where p is a positive integer and γ is a proper fraction which is not equal to α or β. From (iv) it is clear that, when $p\to\infty$, the value of the integral tends to zero. Also from (i) it can be seen that the integrand is holomorphic in ζ, except at the zeros of the denominator. Hence, on evaluating residues, we find that

$$\sum_{n=-\infty}^{\infty}T^{-\kappa}_{n+\alpha}(\cos\theta)T^{-\mu}_{n+\alpha}(\cos\phi)=\sum_{n=-\infty}^{\infty}T^{-\kappa}_{n+\beta}(\cos\theta)T^{-\mu}_{n+\beta}(\cos\phi), \quad \text{(xviii)}$$

where $0<\theta<\pi$, $0<\phi<\pi$, $\kappa+\mu>0$, or, if $\theta\neq\phi$, $0\geqq\kappa+\mu>-1$.

In particular, if $\alpha=-\frac{1}{2}$, $\beta=0$, $\kappa=-\mu$, $\theta\neq\phi$,

$$\sum_{n=-\infty}^{\infty}T^\mu_{n-\frac{1}{2}}(\cos\theta)T^{-\mu}_{n-\frac{1}{2}}(\cos\phi)=\sum_{n=-\infty}^{\infty}T^\mu_n(\cos\theta)T^{-\mu}_n(\cos\phi),$$

and therefore, when m is an integer,

$$\sum_{n=-\infty}^{\infty}\{T^m_{n-\frac{1}{2}}(\cos\theta)T^{-m}_{n-\frac{1}{2}}(\cos\phi)-T^m_{n-\frac{1}{2}}(-\cos\theta)T^{-m}_{n-\frac{1}{2}}(-\cos\phi)\}=0, \quad \text{(xix)}$$

where $0<\theta<\pi$, $0<\phi<\pi$. The restriction $\theta\neq\phi$ may be removed, as this series converges when $\theta=\phi$.

It follows that

$$\int_0^\infty \{T^m_{\lambda-\frac{1}{2}}(\cos\theta)T^{-m}_{\lambda-\frac{1}{2}}(\cos\phi) - T^m_{\lambda-\frac{1}{2}}(-\cos\theta)T^{-m}_{\lambda-\frac{1}{2}}(-\cos\phi)\}d\lambda = 0, \quad . \quad \text{(xx)}$$

where $0<\theta<\pi$, $0<\phi<\pi$, and m is integral.

§ 4. *A Fourier-Legendre Integral Theorem.*—It will now be proved that, if m is an integer and if

$$F(\lambda) = \int_p^q f(\phi)T^m_{\lambda-\frac{1}{2}}(-\cos\phi)\sqrt{(\sin\phi)}d\phi, \quad 0 \leqq p < q \leqq \pi, \qquad . \quad \text{(xxi)}$$

then

$$2\int_0^\infty F(\lambda)\lambda \sin\lambda\pi T^{-m}_{\lambda-\frac{1}{2}}(\cos\theta)\sqrt{(\sin\theta)}d\lambda$$
$$= \begin{bmatrix} \frac{1}{2}\{f(\theta+0)+f(\theta-0)\}, & p<\theta<q, \\ 0, \quad 0<\theta<p \quad \text{or} & q<\theta<\pi. \end{bmatrix} \quad \text{(xxii)}$$

It is assumed that $f(\phi)$ satisfies Dirichlet's conditions in the interval (p, q). As was mentioned in § 1, this theorem was previously established for the particular case $m=0$.

In the first place consider the integral

$$\int_{-h}^{h} E(i\rho\zeta)\{P(-\zeta, \mu, \theta)P(\zeta, \mu, \phi) - 1\}d\zeta,$$

where ρ and h are positive, h is not an integer, and θ and ϕ lie between 0 and π. The integral is taken along the real axis in the ζ-plane indented by small semicircles above the real axis with their centres at the points ± 1, ± 2, ± 3, . . . Now replace this contour by the contour consisting of: (i) the line $\xi=-h$ from $-h$ to $-h+ik$, where k is positive; (ii) the line $\eta=k$ from $-h+ik$ to $h+ik$; (iii) the line $\xi=h$ from $h+ik$ to h. Then it may be shown, just as was done for the large semicircle in § 3, that the integrals along these three lines all tend to zero when h and k tend to infinity. Thus

$$\int_{-h}^{h} E(i\rho\zeta)P(-\zeta, \mu, \theta)P(\zeta, \mu, \phi)d\zeta = \int_{-h}^{h} E(i\rho\xi)d\xi + \tau_1 = \frac{2\sin\rho h}{\rho} + \tau_1,$$

where $\tau_1 \to 0$ when $h \to \infty$. Similarly, by taking a figure which is the reflection of the above figure in the ξ-axis, it can be shown that

$$\int_{-h}^{h} E(-i\rho\zeta)P(-\zeta, \mu, \theta)P(\zeta, \mu, \phi)d\zeta = \frac{2\sin\rho h}{\rho} + \tau_2,$$

where $\tau_2 \to 0$ when $h \to \infty$.

Now consider the integral

$$\int_0^h 2i\sin\lambda\pi d\lambda \int_p^q f(\phi)\begin{bmatrix} E\{i\lambda(\phi-\theta-\pi)\}P(-\lambda, \mu, \theta)P(\lambda, \mu, \phi) \\ -E\{-i\lambda(\phi-\theta-\pi)\}P(\lambda, \mu, \theta)P(-\lambda, \mu, \phi) \end{bmatrix} d\phi \qquad \text{(A)}$$

$$= \int_p^q f(\phi)d\phi \int_{-h}^{h} [E\{i\xi(\phi-\theta)\} - E\{i\xi(\phi-\theta-2\pi)\}]P(-\xi, \mu, \theta)P(\xi, \mu, \phi)d\xi.$$

If $\phi-\theta$ is positive

$$\int_{-h}^{h} \mathrm{E}\{i\zeta(\phi-\theta)\}\mathrm{P}(-\zeta,\mu,\theta)\mathrm{P}(\zeta,\mu,\phi)d\zeta = \frac{2\sin(\phi-\theta)h}{\phi-\theta}+\tau_3,$$

where $\tau_3 \to 0$ when $h\to\infty$; and from (xi) it is clear that the integrals round the indentations at n and $-n$ cancel when the radii tend to zero. The same is true when $\phi-\theta$ is negative, and for the other integrals. Thus the integral (A) is equal to

$$\int_p^q f(\phi)\left\{2\frac{\sin(\phi-\theta)h}{\phi-\theta} - 2\frac{\sin(\phi-\theta-2\pi)h}{\phi-\theta-2\pi}+\tau\right\}d\phi,$$

where $\tau\to 0$ when $h\to\infty$. Hence, when $h\to\infty$, integral (A) tends to

$$\begin{bmatrix}\pi\{f(\theta+0)+f(\theta-0)\}, & p<\theta<q, \\ 0, & 0<\theta<p \text{ or } q<\theta<\pi.\end{bmatrix}$$

Now pick out the real part of the integral with the help of (xiii), and divide by 2π; then

$$\int_0^\infty \frac{\lambda d\lambda}{2\cos(\lambda+\mu)\pi}\int_p^q f(\phi)\sqrt{(\sin\theta\sin\phi)}$$

$$\times\begin{bmatrix}\cos\lambda\pi\begin{Bmatrix}-\mathrm{T}(\lambda,-\mu,\theta)\mathrm{T}(\lambda,\mu,\phi)+\mathrm{T}(\lambda,\mu,\theta)\mathrm{T}(\lambda,-\mu,\phi) \\ +\mathrm{T}(\lambda,-\mu,\pi-\theta)\mathrm{T}(\lambda,\mu,\pi-\phi)-\mathrm{T}(\lambda,\mu,\pi-\theta)\mathrm{T}(\lambda,-\mu,\pi-\phi)\end{Bmatrix} \\ -\sin\mu\pi\{\mathrm{T}(\lambda,-\mu,\pi-\theta)\mathrm{T}(\lambda,\mu,\phi)+\mathrm{T}(\lambda,\mu,\pi-\theta)\mathrm{T}(\lambda,-\mu,\phi)\} \\ +\sin(2\lambda+\mu)\pi\{\mathrm{T}(\lambda,-\mu,\theta)\mathrm{T}(\lambda,\mu,\pi-\phi)+\mathrm{T}(\lambda,\mu,\theta)\mathrm{T}(\lambda,-\mu,\pi-\phi)\}\end{bmatrix}d\phi$$

$$=\begin{bmatrix}\tfrac{1}{2}\{f(\theta+0)+f(\theta-0)\}, & p<\theta<q, \\ 0, & 0<\theta<p \text{ or } q<\theta<\pi.\end{bmatrix} \quad . \quad . \quad . \text{ (xxiii)}$$

From (xv) it follows that, if m is an integer, the integral

$$\int_0^\infty 2\lambda\sin\lambda\pi d\lambda\int_p^q f(\phi)\mathrm{T}(\lambda,-m,\theta)\mathrm{T}(\lambda,m,\pi-\phi)\sqrt{(\sin\theta\sin\phi)}d\phi$$

has the same value. From this the theorem given by (xxi) and (xxii) follows. The imaginary part of the integral gives, when m is an integer,

$$\int_0^\infty \lambda\tan\lambda\pi d\lambda\int_p^q f(\phi)\sqrt{(\sin\theta\sin\phi)}$$

$$\times\{\mathrm{T}_{\lambda-\frac{1}{2}}^{-m}(\cos\theta)\mathrm{T}_{\lambda-\frac{1}{2}}^{m}(\cos\phi)-\mathrm{T}_{\lambda-\frac{1}{2}}^{-m}(-\cos\theta)\mathrm{T}_{\lambda-\frac{1}{2}}^{m}(-\cos\phi)\}d\phi=0. \qquad \text{(xxiv)}$$

§ 5. *Integral Evaluated by Fourier's Integral Theorem.*—The formula to be established is

$$\int_0^\infty \mathrm{T}_{\lambda-\frac{1}{2}}^{m+\frac{1}{2}}(\cos\theta)\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)\sin\theta d\lambda=\tfrac{1}{2}(-1)^m, \quad . \quad . \text{ (xxv)}$$

where m is zero or a positive integer and $0<\theta<\pi$.

The Mehler-Dirichlet Formula may be written

$$(\sin\theta)^{m+\frac{1}{2}}\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)=\frac{1}{\Gamma(m+1)\sqrt{(2\pi)}}\int_{-\theta}^{\theta}e^{i\lambda\phi}(\cos\phi-\cos\theta)^m d\phi, \quad \text{(xxvi)}$$

where $0<\theta<\pi$, $m>-1$. If m is a positive integer, this becomes, on integration by parts,

$$(\sin\theta)^{m+\frac{1}{2}}\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)=\frac{1}{\Gamma(m+1)\sqrt{(2\pi)}}$$

$$\times\left[\begin{array}{l}\dfrac{e^{i\lambda\phi}}{i\lambda}(\cos\phi-\cos\theta)^m-\dfrac{e^{i\lambda\phi}}{(i\lambda)^2}m(\cos\phi-\cos\theta)^{m-1}(-\sin\phi)\\ +\;.\;.\;.+\displaystyle\int\frac{e^{i\lambda\phi}}{(i\lambda)^m}\{m\,!\,(\sin\phi)^m+(\cos\phi-\cos\theta)(\quad\ )\}d\phi\end{array}\right]_{-\theta}^{\theta}$$

$$=\frac{1}{\sqrt{(2\pi)}}\int_{-\theta}^{\theta}\frac{e^{i\lambda\phi}}{(i\lambda)^m}\{(\sin\phi)^m+(\cos\phi-\cos\theta)(\quad\ )\}d\phi.$$

Hence, by Fourier's Integral Theorem,

$$\int_{-\infty}^{\infty}e^{-i\lambda t}(i\lambda)^m(\sin\theta)^{m+\frac{1}{2}}\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)d\lambda$$

$$=\left[\begin{array}{ll}\sqrt{(2\pi)}\{(\sin t)^m+(\cos t-\cos\theta)(\quad\ )\}, & |t|<\theta,\\ 0 \qquad\qquad\qquad\qquad\qquad\qquad\quad , & |t|>\theta,\\ \frac{1}{2}\sqrt{(2\pi)}(\sin\theta)^m \qquad\qquad\quad\ , & t=\theta.\end{array}\right.$$

Therefore, if m is zero or a positive integer,

$$\int_{-\infty}^{\infty}e^{-i\lambda\theta}(i\lambda)^m\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)\sqrt{(\sin\theta)}d\lambda=\tfrac{1}{2}\sqrt{(2\pi)},$$

or

$$\int_{0}^{\infty}\{e^{-i\lambda\theta}(-i\lambda)^m+e^{i\lambda\theta}(i\lambda)^m\}\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)\sqrt{(\sin\theta)}d\lambda=(-1)^m\tfrac{1}{2}\sqrt{(2\pi)}. \quad \text{(xxvii)}$$

Similarly, if r is a positive integer (or zero) less than m,

$$\int_{0}^{\infty}\{e^{-i\lambda\theta}(-i\lambda)^r+e^{i\lambda\theta}(i\lambda)^r\}\mathrm{T}_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)d\lambda=0. \quad .\quad .\ \text{(xxviii)}$$

Now, from (iv) and (v), noting that $\mathrm{P}(\lambda, \mu, \theta)$ and $\mathrm{P}(\lambda, \mu, -\theta)$ can be interchanged by changing i into $-i$, it is seen that

$$\sqrt{(2\pi\sin\theta)}\mathrm{T}(\lambda, m+\tfrac{1}{2}, \theta)=\mathrm{E}(-i\lambda\theta)\{\mathrm{F}(-i\lambda)-i\mathrm{G}(-i\lambda)\}+\mathrm{E}(i\lambda\theta)\{\mathrm{F}(i\lambda)+i\mathrm{G}(i\lambda)\},$$

where $\mathrm{F}(x)$ is a polynomial of degree m in x with real coefficients and with unity as the coefficient of x^m, and $\mathrm{G}(x)$ is a polynomial of degree less than m in x with real coefficients. Thus

$$\int_{0}^{\infty}\sqrt{(2\pi\sin\theta)}\mathrm{T}(\lambda, m+\tfrac{1}{2}, \theta)\mathrm{T}(\lambda, -m-\tfrac{1}{2}, \theta)d\lambda$$

$$=\tfrac{1}{2}\int_{-\infty}^{\infty}\left[\begin{array}{l}\mathrm{E}(-i\lambda\theta)\{\mathrm{F}(-i\lambda)-i\mathrm{G}(-i\lambda)\}\\ +\mathrm{E}(i\lambda\theta)\{\mathrm{F}(i\lambda)+i\mathrm{G}(i\lambda)\}\end{array}\right]\mathrm{T}(\lambda, -m-\tfrac{1}{2}, \theta)d\lambda$$

$$=\int_{0}^{\infty}\{\mathrm{E}(-i\lambda\theta)\mathrm{F}(-i\lambda)+\mathrm{E}(i\lambda\theta)\mathrm{F}(i\lambda)\}\mathrm{T}(\lambda, -m-\tfrac{1}{2}, \theta)d\lambda.$$

From this, with (xxvii) and (xxviii), (xxv) is obtained. Also

$$\int_0^\infty T_{\lambda-\frac{1}{2}}^{r+\frac{1}{2}}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)d\lambda=0, \qquad . \quad . \quad . \text{(xxix)}$$

where r is a positive integer (or zero) less then m, and $0<\theta<\pi$.

§ 6. *Evaluation of Integrals by Means of Series.*—Consider the integral of

$$T_{\zeta-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\zeta-\frac{1}{2}}^{-\mu}(\cos\phi)\frac{1}{(\zeta-\lambda)\sin\pi\zeta},$$

where $0<\theta<\pi$, $0<\phi<\pi$, $\theta+\phi\leqq\pi$, $\kappa+\mu>-1$, taken round the circle $|\zeta|=p+\frac{1}{2}$, where p is a positive integer. As in the case of the similar integral in § 3, it can be shown, by letting p tend to infinity and evaluating the residues, that

$$T_{\lambda-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(\cos\phi)$$
$$=\frac{\sin\pi\lambda}{\pi}\sum_{n=-\infty}^{\infty}(-1)^n\frac{1}{\lambda-n}T_{n-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{n-\frac{1}{2}}^{-\mu}(\cos\phi), \qquad \text{(xxx)}$$

where $0<\theta<\pi$, $0<\phi<\pi$, $\theta+\phi\leqq\pi$, $\kappa+\mu>-1$.

It follows that

$$\int_0^\infty \cos\lambda\pi T(\lambda,-\kappa,\theta)T(\lambda,-\mu,\phi)d\lambda$$
$$=\frac{1}{2}\int_{-\infty}^\infty \cos\lambda\pi T(\lambda,-\kappa,\theta)T(\lambda,-\mu,\phi)d\lambda$$
$$=\frac{1}{4\pi}\sum_{n=-\infty}^{\infty}(-1)^n T(n,-\kappa,\theta)T(n,-\mu,\phi)\int_{-\infty}^\infty\frac{\sin 2\pi\lambda}{\lambda-n}d\lambda$$
$$=\frac{1}{4}\sum_{n=-\infty}^{\infty}(-1)^n T(n,-\kappa,\theta)T(n,-\mu,\phi).$$

Now the integral

$$\frac{1}{2\pi i}\int T_{\zeta-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\zeta-\frac{1}{2}}^{-\mu}(\cos\phi)\frac{\pi d\zeta}{\sin\pi\zeta}, \qquad . \quad . \quad . \quad \text{(B)}$$

where $0<\theta<\pi$, $0<\phi<\pi$, $\theta+\phi\leqq\pi$, $\kappa+\mu>0$, taken round the circle $|\zeta|=p+\frac{1}{2}$, tends to zero when $p\to\infty$. If $0\geqq\kappa+\mu>-1$ this is also the case if $\theta+\phi<\pi$. Hence, on evaluating the residues, we have

$$\sum_{n=-\infty}^{\infty}(-1)^n T_{n-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{n-\frac{1}{2}}^{-\mu}(\cos\phi)=0, \qquad . \quad . \quad . \text{(xxxi)}$$

and therefore

$$\int_0^\infty \cos\lambda\pi T_{\lambda-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(\cos\phi)d\lambda=0, \qquad . \quad . \quad \text{(xxxii)}$$

where, in both cases, $0<\theta<\pi$, $0<\phi<\pi$, $\theta+\phi\leqq\pi$ and $\kappa+\mu>0$ or $\theta+\phi<\pi$ and $0\geqq\kappa+\mu>-1$.

Again, if $\kappa+\mu=0$ and $\theta+\phi=\pi$, so that $\cos\phi=-\cos\theta$, the integrand in (B), multiplied by ζ, tends to $1/\sin\theta$ both above and below the real axis when $p\to\infty$. Hence

$$\sum_{n=-\infty}^{\infty}(-1)^n T_{n-\frac{1}{2}}^{\mu}(\cos\theta)T_{n-\frac{1}{2}}^{-\mu}(-\cos\theta)=\frac{1}{\sin\theta}, \quad . \quad \text{(xxxiii)}$$

where $0<\theta<\pi$, and therefore

$$\int_0^{\infty}\cos\lambda\pi T_{\lambda-\frac{1}{2}}^{\mu}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(-\cos\theta)\sin\theta d\lambda=\tfrac{1}{2}, \quad . \quad \text{(xxxiv)}$$

where $0<\theta<\pi$.

Again, from (xxx)

$$\int_0^{\infty}T_{\lambda-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(\cos\phi)d\lambda=\tfrac{1}{2}\int_{-\infty}^{\infty}T_{\lambda-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(\cos\phi)d\lambda$$
$$=\frac{1}{2\pi}\sum_{n=-\infty}^{\infty}(-1)^n T_{n-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{n-\frac{1}{2}}^{-\mu}(\cos\phi)\int_{-\infty}^{\infty}\frac{\sin\pi\lambda}{\lambda-n}d\lambda,$$

and therefore

$$\int_0^{\infty}T_{\lambda-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-\mu}(\cos\phi)d\lambda=\tfrac{1}{2}\sum_{n=-\infty}^{\infty}T_{n-\frac{1}{2}}^{-\kappa}(\cos\theta)T_{n-\frac{1}{2}}^{-\mu}(\cos\phi), \quad \text{(xxxv)}$$

where $0<\theta<\pi, 0<\phi<\pi, \theta+\phi\leqq\pi$, and $\kappa+\mu>0$; or, if $\theta\neq\phi, 0\geqq\kappa+\mu>-1$.

If $\kappa+\mu=0$ and $\mu=m+\frac{1}{2}$, where m is integral, the integral converges even when $\phi=\theta$. Hence

$$\int_0^{\infty}T_{\lambda-\frac{1}{2}}^{m+\frac{1}{2}}(\cos\theta)T_{\lambda-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)d\lambda=\tfrac{1}{2}\sum_{n=-\infty}^{\infty}T_{n-\frac{1}{2}}^{m+\frac{1}{2}}(\cos\theta)T_{n-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta), \quad \text{(xxxvi)}$$

where $0<\theta\leqq\frac{1}{2}\pi$.

On comparing this result with (xxv) we see that, if m is zero or a positive integer,

$$\sum_{n=-\infty}^{\infty}T_{n-\frac{1}{2}}^{m+\frac{1}{2}}(\cos\theta)T_{n-\frac{1}{2}}^{-m-\frac{1}{2}}(\cos\theta)=\frac{(-1)^m}{\sin\theta}, \quad . \quad \text{(xxxvii)}$$

where $0<\theta<\pi$. The proof is only valid for $0<\theta\leqq\frac{1}{2}\pi$; but the complete result can be obtained from (xxxiii) by putting $\pi-\theta$ in place of θ and then applying (viii) when $\mu=m+\frac{1}{2}$.

In (xxxi) and (xxxii) multiply by

$$\Gamma(1+\kappa)\left(\frac{1+\cos\theta}{1-\cos\theta}\right)^{\frac{1}{2}\kappa}$$

and let $\theta\to 0$; then from (i) we see that

$$\sum_{n=-\infty}^{\infty}(-1)^n T_{n-\frac{1}{2}}^{-\mu}(\cos\phi)=0 \quad . \quad . \quad . \quad \text{(xxxviii)}$$

and

$$\int_0^\infty \cos \lambda\pi \mathrm{T}^{-\mu}_{\lambda-\frac{1}{2}}(\cos \phi)d\lambda = 0, \quad . \quad . \quad . \qquad \text{(xxxix)}$$

where in both cases $0<\phi<\pi$, $\mu> -\frac{1}{2}$.

Similarly, from (xxxv),

$$\int_0^\infty \mathrm{T}^{-\mu}_{\lambda-\frac{1}{2}}(\cos \phi)d\lambda = \tfrac{1}{2} \sum_{n=-\infty}^{\infty} \mathrm{T}^{-\mu}_{n-\frac{1}{2}}(\cos \phi), \quad . \quad . \quad . \qquad \text{(xl)}$$

where $0<\phi<\pi$, $\mu> -\frac{1}{2}$.

Formulæ (xxxix) and (xl) may also be derived by means of the expansion

$$\mathrm{T}^{-\mu}_{\lambda-\frac{1}{2}}(\cos \phi) = \frac{\sin \pi\lambda}{\pi} \sum_{n=-\infty}^{\infty} (-1)^n \frac{1}{\lambda - n} \mathrm{T}^{-\mu}_{n-\frac{1}{2}}(\cos \phi), \quad . \quad . \qquad \text{(xli)}$$

where $\mu> -\frac{3}{2}$, $0<\phi<\pi$. This formula and (xxxviii) can be established by integrating

$$\mathrm{T}^{-\mu}_{\zeta-\frac{1}{2}}(\cos \phi)\frac{1}{(\zeta-\lambda)\sin \pi\zeta} \quad \text{and} \quad \mathrm{T}^{-\mu}_{\zeta-\frac{1}{2}}(\cos \phi)\frac{1}{\sin \pi\zeta}$$

respectively round large circles with the origin as centre.

(*Issued separately July* 16, 1934.)

XIV.—Fifty Years Ago, in the Royal Society of Edinburgh. By **Professor D'Arcy Wentworth Thompson.** (With Two Plates.) (An Address delivered, at the request of the Council, on May 7, 1934, in commemoration of the 150th Year of the Society.)

FIFTY years ago, when this Royal Society was a hundred years old, it fell to Lord Moncrieff, the President, to speak to the occasion. He sketched the history of the Society through its hundred years, and dwelt most on the days when it was born. He told how the Founders made their way one winter's night from homes in Lawnmarket or Canongate to the College Library (as Johnson and Boswell had lately done), with a few flickering oil-lamps to light the way and tallow-candles which dimly lit the room.

He spoke proudly of the twelve Judges of Session who were original members of our Society; of the learned, scholarly gentlemen, the Dundases of Arniston, the Duke of Buccleuch, Sir James Hall of Dunglass, afterwards President, and many more; of the philosophers and men of letters, Adam Smith, and Dugald Stewart and Henry Mackenzie; of the natural philosophers, James Playfair the mathematician, a pillar of our Society for many years; Alexander Monro the anatomist, second of his name; of James Hutton the geologist, William Cullen the physician, Joseph Black the chemist. Many of these were in the front line of European learning and reputation, and history records their names among those who laid the foundations of the sciences.

Once in a way, to this country or that, there comes a Golden Age of art and learning. It does not last long, sometimes only for a generation; but its fame and its example endure for ever. This Society of ours was part of such a golden harvest!

Fifty years later, a hundred years ago, the British Association, three years old, came to Edinburgh and met (in part at least) in the meeting-room of our Society. Our President, Sir Thomas Makdougall-Brisbane, was President of the Association; Sir David Brewster was one of its Vice-Presidents; and its General Secretary was our Secretary, Sir John Robison, son of him whose beautiful portrait by Raeburn hangs in the next room. The sciences which Black and Hutton and Sir James Hall

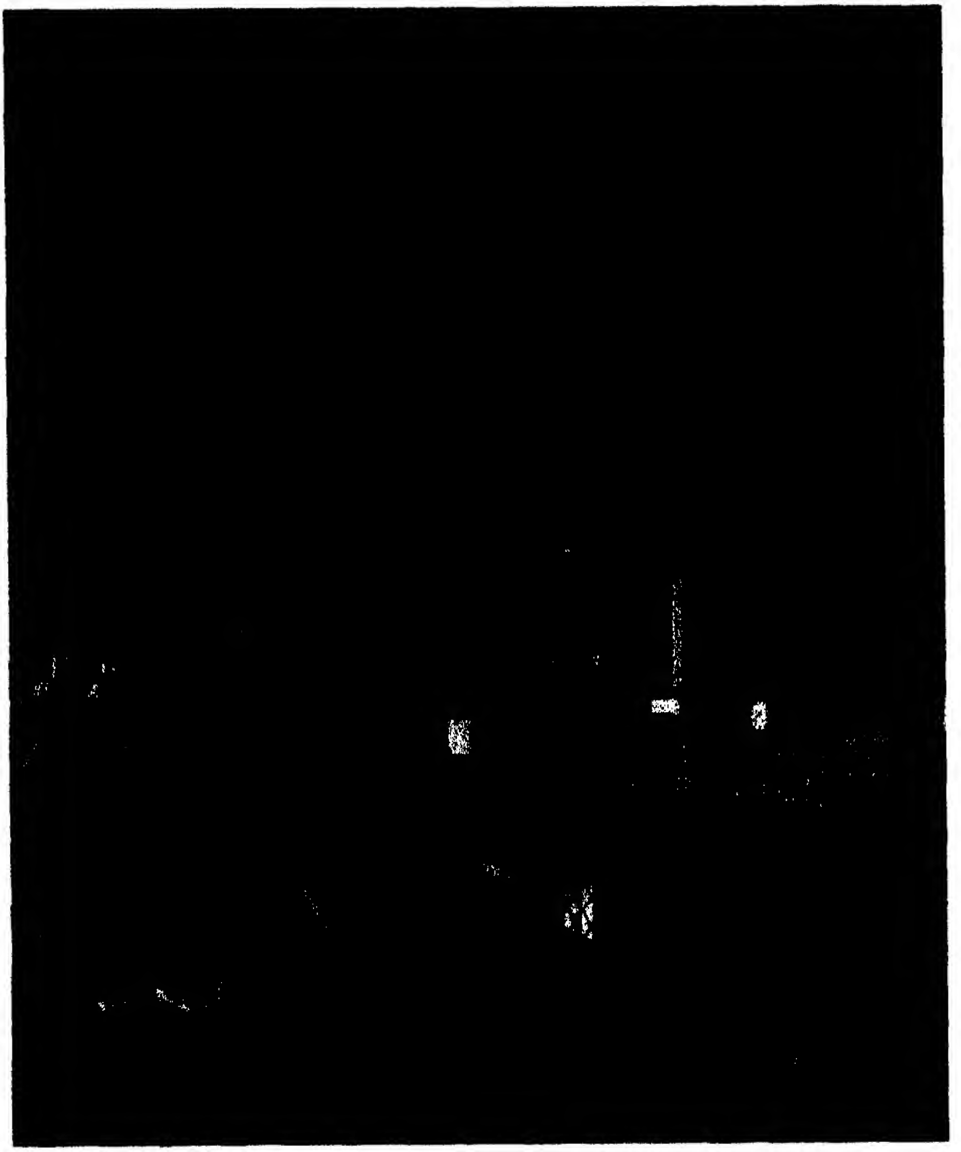
had helped to create were now established. Adam Sedgwick, "the old Adam" Sedgwick of the Cambrian System, was here, and met in our rooms, as kindred spirits, Dr Fleming who had given its name to the Old Red Sandstone, and Samuel Hibbert the first discoverer of its fossil fishes.

Arago came from Paris; he had friends here, Brewster and Playfair among the rest, and had written the article on Polarization of Light for the *Encyclopædia Britannica*. This time he brought plans for a magnetic survey of the world, and was in close touch with our President, who had begun his famous Makerstoun observations and was doing more than any other man to bring to light the mysteries of terrestrial magnetism.

If I mistake not, Agassiz was also here; and certainly Robert Brown, whom Humboldt had called *facile princeps botanicorum*,—who discovered the Brownian movement and gave its name to the nucleus of the cell, and had a something of Faraday's instinct and genius for discovery. Not least, Sir William Rowan Hamilton was here, whom Tait, then a child, worshipped afterwards on this side idolatry and held to be the very prince of mathematicians. All these came to Edinburgh a hundred years ago, and were welcomed and entertained by our Society.

Fifty more years go by; it is fifty years ago, and the Society is a hundred years old. We are now looking back on a remembered road which in part or whole we all have travelled. It profits us to look backward now and then; it is a peculiar pleasure and indulgence and consolation of the old. Some of us have been so long upon our journey that fifty years or sixty years are easy to recall. The days when we were young are remembered when the years between are forgot. The kindly men who taught us in the outset have befriended us all the way, and the things which they showed us have been a help to us in our journey.

Fifty years ago things were vastly different, here and the whole world over, to what they had been in that Old Edinburgh in which our Society began. There seemed little left to discover! The wonderful nineteenth century was growing old. We were living in the easy comfort of the Victorian age. But changes were coming all too soon. Electric light, the gramophone and the telephone are coming; they have been experimenting with the last in Tait's laboratory, and Fleeming Jenkin brought us the phonograph, with its tiny tinfoil records, not long ago. The typewriter will be clattering, and moving pictures flickering on the screen. Carriages will run without horses; and we shall be flying, as the crow flies, to Paris and the ends of the earth. Max Planck will come, and Einstein and Rutherford, and the foundations of Natural Philosophy



Royal Society's Apartments, Royal Institution, Edinburgh.
The Reading-Room.

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will tremble. Kingdoms will vanish, and Empires crumble away! Let us step across Princes Street, and find a haven in the rooms of the Royal Society!

We pass through a vestibule and enter those beautiful apartments, one opening into another, at which some of us still glance enviously through the tall pillared windows at the foot of the Mound. In the first room at a table which we use still an old man sat, surrounded by books, reading all day long. It has been said of him that few men absorbed more learning, and exuded less! He was the Society's Librarian, Mr James Gordon. He had obviously come out of another age. He wore an old-fashioned swallow-tail coat, and a black satin stock came close up to his clean-shaven chin. He had a shy but dignified manner, and a hesitation, almost a stammer, in his speech. He made you think of Dominie Sampson, but he was a greater man. He was a little like his friend Veitch, the great Hellenist; but Veitch left, as Gordon could not, a monument of his learning.

Gordon wrote to perfection the fluent sonorous Latin of the cosmopolitan scholar. He loved to write addresses for the Society to convey to a foreign university or academy. He wrote one when Wyville Thomson went to Upsala, in 1878, for the centenary of the death of Linnæus; and I remember hearing Wyville tell how much this address had been admired by the Swedish scholars. So we looked for it the other day, and found it in our Minutes: *Amplissimis Curatoribus, Rectori Magnifico, Doctissimoque Senatui Universitatis Upsaliensis: Societas Regia Edinensis nos jussit, viri illustrissimi, vobis hoc solemni die gratulari, quo nihil exoptatius nobis evenire potest*—and so on. Gordon was, like Veitch, a hospitable man, even convivial, in an old-fashioned and decorous way. He used to give little tea-parties, where (over the toddy) they sang songs—as everybody did in those days, judges, doctors and professors! When he grew too old to sing he would make the others sing—such songs as "A wee bird cam to oor ha' door": till the tears ran down his cheeks —for he was one of the last of the Jacobites!

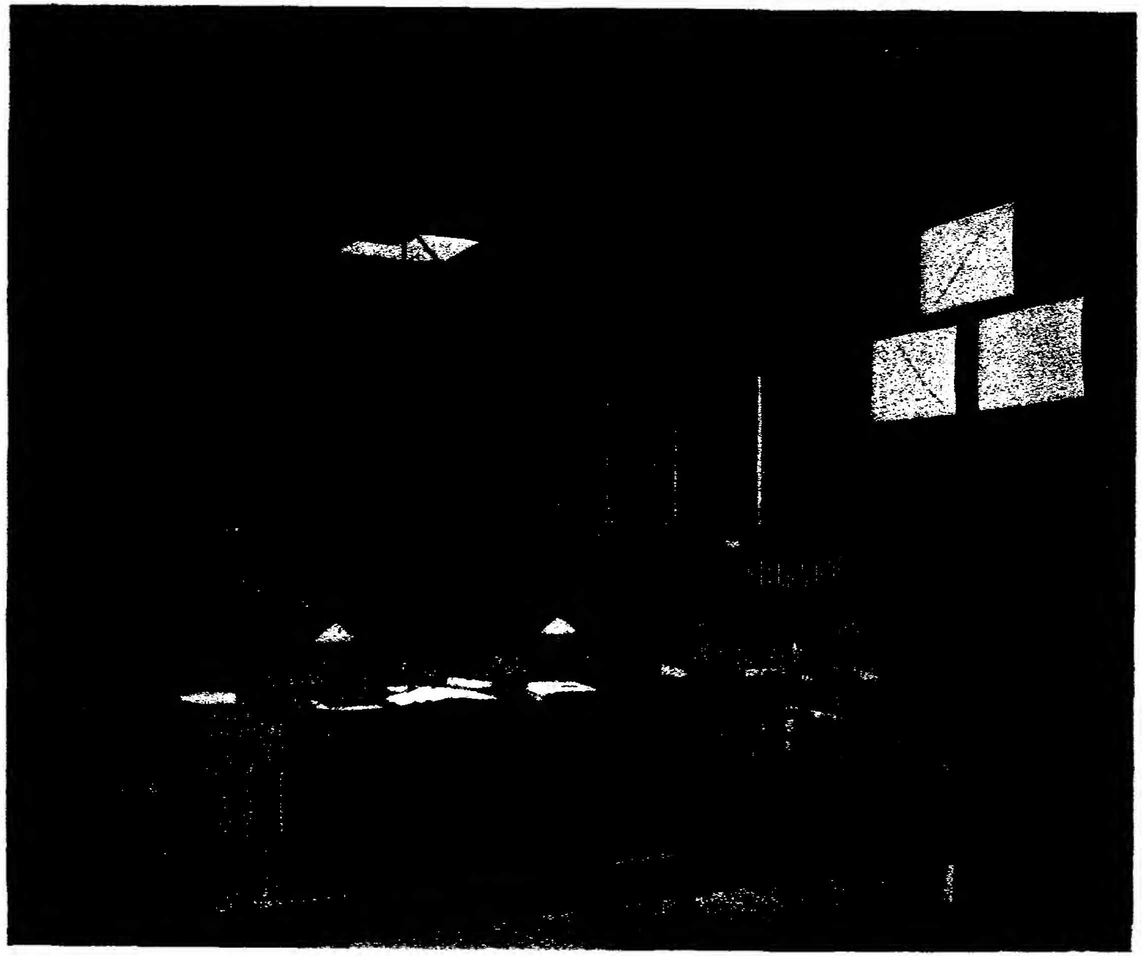
In the next room, a long and beautiful room, our meetings were held. Five large windows looked out on the Castle and the Gardens; but the meetings were at eight o'clock, and the curtains were drawn. Opposite the windows the bookcases were kept low, and there the portraits hung—our Walter Scott, and James D. Forbes, and Sir David Brewster, and Sir T. Makdougall-Brisbane, and Raeburn's portrait of John Robison the elder, and later on George Reid's portraits of Sir Robert Christison and of Tait. Half-way up the room on the window side was the President's chair, raised a little, and the table where the secretaries and other

officers sat. On the far side, looking down the room towards the entrance, Tait sat for nearly forty years. I think of Crum Brown, wearing his little velvet cap, sitting beside Tait; of Buchan at the opposite corner, stroking now and then his long red-brown beard; and Kelvin's eager, restless figure in the chair.

On either side of the table were a few benches, of horsehair and mahogany, for members and their friends. Facing the President, across the Turkey carpet, the reader had a little table of his own and a black-board of no great size. The whole plan and idea of the chamber was different from this lecture-room of ours; it was the old-fashioned salon of an academy.

Let me borrow a few words from Dr Cargill Knott—who afterwards was our General Secretary for ten years. It seems but yesterday, he says, when Piazzi Smyth, with the peculiar hesitation in his speech, uttered his éloge of Leverrier in the quaint-wrought involved sentences of a bygone century. Or it was Kelvin moving eagerly on the soft carpet, and putting his gyrostats through their dynamical drill; or Fleeming Jenkin amusing and instructing the audience with the sound of the first phonograph, as he used it to analyse human speech; or Lister quaffing a glass of milk which had stood for weeks under a light stopper which no germs could creep through; or Turner demonstrating whales' bones or human skulls; or Tait himself talking, in easy words, about strains and mirage, or the kinetic theory of gases, or the spin of golf-balls.

Let us go a little farther and recall a certain meeting, not fifty but sixty years ago—sixty years almost to a day. David Milne-Home was in the chair, and papers of the usual kind were being read. Professor Turner had a rare beast, the two-toed sloth, and was eager to describe its anatomy. George Forbes (to-day one of the oldest of our Fellows), son of Tait's illustrious predecessor, talked of an optical illusion which Tait had noticed one sleepless night, and in which Crum Brown and he were greatly interested. Edward Sang had something to say on the properties of fluid drops within crystal cavities. And then a paper was read by a young author, rather a dull paper, "On the Thermal Influence of Forests." It dealt with the island of Malta, where the Chairman had a scheme for the planting of trees. It made a good show of meteorological learning, quoting Réaumur, Humboldt, Becquerel, Boussingault, and Scoresby-Jackson's Medical Climatology. Its style was technical and scientific, rather than literary: "In addition to the ordinary hours of observation, special readings of the thermometer should be made as often as possible at a change of wind, in order to admit of the recognition and extension of Herr Rivoli's comparison,"—and so on. It



Royal Society's Apartments, Royal Institution, Edinburgh.
The Lecture-Room.

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was one of the first things the author ever published, and almost the only scientific thing he ever wrote. He did better, much better, ten years later on, when he wrote a book called *Treasure Island*!

The Society used to meet in the evening, as I have said; and afterwards, late as it was, members used to go on to an evening club. It met for talk and talk alone, in an upper room in George Street, and was served by a butler who was somebody else's butler during the day. Tait and Masson and Matthews Duncan were among its founders, and Donaldson, afterwards of St Andrews, and Sheriff "Sandy" Nicolson who wrote the Song of Skye and "The British Ass.," and "Jack" McLennan who wrote on *Primitive Marriage*, to the amusement of his brother advocates but to his own lasting fame as one of the founders of anthropology! After these came Tulloch, and Lewis Campbell, and George Ramsay, and Sir William Stirling-Maxwell, and George Reid, and Robertson Smith, and Sir William Thomson himself, once in a way; and Tait brought distinguished guests like Huxley and Cayley and Sylvester and Clifford; and there was nothing to do—no cards, no supper—only to smoke Long Broseley churchwarden pipes, and listen to talk that I daresay had scarce its equal in the world!

Fifty years ago, in the very year in which our Society was a hundred years old, the University of Edinburgh was three hundred years old. Fifty years before (as we have seen) the British Association had brought famous men to our rooms; and now the same thing happened over again, for the University brought guests from all over the world. One night, with Thomson in the chair, Luigi Cremona (one of those great mathematicians whom Italy never ceases to produce) read a paper, and von Helmholtz, physiologist, physicist and mathematician, read another. With these had come Cayley and Sylvester, Rayleigh and Stokes, Hermite and Emile Picard. Our then Vice-President, Lord McLaren, no mean mathematician himself, invited them all along with Tait and Thomson one night to dinner; and Chrystal, writing twenty years after, said there had probably been no such feast of mathematicians before or since. Long after all the rest are gone, Emile Picard, Hermite's son-in-law, Secretary of the French Academy, lives and goes about his work to-day.

The Tercentenary was soon over; but then and for long after two other events influenced our Society and the scientific world of Edinburgh. One was the return of the "Challenger" Expedition; the other was the publication of the famous ninth edition of the *Britannica*. Edinburgh was the home of encyclopædias. In the early sixties Chambers's *Encyclopædia* was being published; and Tait, just come to Edinburgh, wrote article after article for it, including a well-known one on Quaternions which is there

still. It was then that Dr Findlater, editor of *Chambers'*, taught Tait to play golf, and that Tait went to live in Greenhill Gardens that he might get his daily morning round on Bruntsfield Links! A certain lesser encyclopædia was a godsend to some of us younger men, even in our student days; for Knott was its scientific editor, and I and others wrote countless columns under his kindly guidance, in days when money was scarce and to earn it was the only way of getting it! The *Britannica* was for the older and wiser men, and it was only an occasional crumb that fell to us from its table. But just as Robison and Playfair and Brewster and Dugald Stewart, and other members of our young Society, had been contributors to earlier editions, so fifty and sixty years ago, under Baynes and Robertson Smith, scientific Edinburgh was kept busy writing articles, and who should do this and who should get that was eagerly discussed. I can remember a little outburst of Tait's, when "Astronomy" went to a certain popular writer whom Tait held to be outside the pale! But soon afterwards Clerk Maxwell drew up a scheme for the chief scientific articles, and himself wrote the article Atom, in which Kelvin's vortex-atoms, by the way, had full justice done them; and then a beautiful article on Capillarity; and Tait wrote on Light and on Mechanics; and Chrystal wrote famous articles on Electricity and Magnetism; and Crum Brown wrote a most original article on "Molecule." Besides these and such as these there were endless biographical articles: Tait's on Sir William Rowan Hamilton among the chief, and Chrystal's on Pascal, Poisson, Riemann, and many more. It was a busy time when all these were being written.

As the encyclopædia brought the learning of Great Britain to an Edinburgh printing house, so did the "Challenger" Expedition make Edinburgh a centre for the naturalists of the world. Wyville Thomson was a weary man and out of health when he came home from the sea, and he died before his work was done. John Murray, the strong, able man who took his place and filled it nobly, has overshadowed Wyville's name and memory; but we few who knew him hold him in honour and affection. He had begun as a boy naturalist by the East Lothian shore, as did old Sir John Graham Dalyell, and Francis Maitland Balfour, and many and many another. He came under the potent influence of Edward Forbes, who, with Goodsir, borrowed the oysterman's dredge and began the endless task of the exploration of the sea. With Carpenter, Wyville explored our western waters in the "Porcupine," and made the cardinal discovery of the warm and cold waters of the Faeroe Channel, on either side of the submarine ridge which bears his name. We owe to him the grandiose conception, the splendid programme and the immense

achievement of the "Challenger" Expedition; and the planning on a noble scale of the publication of its results. He saw before he died a few parts of the great publication.

He was a kindly man and faithful to his friends. He would search all Europe and America too to find the best man to deal with this group of animals or that; but if he found no such specialist he would pick out some friendly naturalist at home, or some young pupil of his own; and he made no mistakes in doing so. He gave a certain large and difficult group to my old school-fellow Willie (afterwards Sir William) Herdman; and Herdman brought his first reports before this Society, and became in course of time the chief authority on the Tunicates in the world.

Herdman was a schoolboy at the Edinburgh Academy sixty years ago and more, and three other boys sitting in the same small class all became Fellows of this Society; to one of these four, Dr J. S. Haldane, we are to-day paying the highest compliment in our power! Some five and twenty years before, other four boys were at the Academy together, all Fellows of our Society in after years—Tait and Fleeming Jenkin and Lewis Campbell, and Clerk Maxwell who towers over all. Maxwell paid our Society his first visit when he was twelve years old. At fifteen he wrote his first paper for us on the Properties of certain Oval Curves—we still have the manuscript, in his schoolboy hand; and when he was sixteen, a student under Forbes, he wrote another on Rolling Curves or Roulettes. But Forbes had to read both of these papers, for it was not thought proper for a boy in a round jacket to address the Society! Maxwell read a famous paper to us on Reciprocal Figures, in 1870, nine years before his untimely death. He was the greatest mathematical physicist, the greatest physicist after Faraday, in all the nineteenth century.

Fleeming Jenkin was a man of lesser genius but of great ability, and many curious accomplishments. He had much to do, under Sir William Thomson, with the laying of the early ocean cables, and in later years he brought many interesting things before the Society—such as the phonograph, and an invention of his own for the transport of goods, which he called telpherage. Many still remember his hospitable house, where Stevenson and Henley used to come with troops and troops of friends.

Let us think of a few more who were men of mark here fifty years ago. As to Lord Kelvin, I can add nothing to what has been so often said, of one who is so well remembered. He was a Fellow of the Society for sixty years. His papers on the theory of heat, on hydrodynamical questions, on vortex atoms, on gyrostats, on close-packing of atoms, and what not more, adorned our *Transactions* for a long generation. He was the unquestioned leader of the Society, the master of all. He

was President until his death, except for the few years when that office was incompatible with his presidency of the Royal Society of London.

Alexander Buchan sat at the table for years, a tall and striking figure. He was a humorous man, and showed it by the twinkle in his eye; he said once: "Everybody thinks me taller than I am, and wiser than I am, and better than I am": this last having something to do with the fact that he was an elder under Dr Whyte in Free St George's. The "spells" which have made his name a household word have little to do with his real fame. Seventy years ago he had made a European reputation: for he had mapped the isobars and isotherms of the world, and laid the foundations of all we know of atmospheric circulation. He was probably the very first to show that "weather travels": on which cardinal fact all our weather-forecasting is based. He had a deal to do with the starting of the observatory on Ben Nevis, half a century ago, in which this Society was deeply interested.

Dr Edward Sang, a teacher of mathematics in Edinburgh, died some forty years ago; he had been a candidate for the Natural Philosophy Chair when Tait won it over Clerk Maxwell. Fifty years ago, an old man, Sang was busy constructing his wonderful Tables of Logarithms, which have never been printed but are among the Society's most prized possessions. They were among the first tables to be independently calculated since Briggs and Vlacq made theirs, immediately after the Canon Mirificus. All but a hundred years ago Sang had read a paper to us on the action of Nicol's polarizing prism, Nicol being an Edinburgh optician who had just invented this indispensable instrument. Sang's paper was never published, no one knows why; and when he was dying he spoke of it to Tait, and said he thought he had never written a better thing. Tait made instant search among our files for the paper, had it read and printed—but poor Sang was dead. Had it been published when it was written it would have been one of the most important scientific papers of the time; it contained things which were not said again for nearly fifty years.

One of our greatest, oldest and most famous members, Sir Thomas Muir, once a Glasgow schoolmaster, died but a few weeks ago. He was known to few of us, for he had lived for many years at the Cape. He sent us, fifty years ago and on almost to the last, a long series of papers on the Theory of Determinants. He strove continually (so it has been said of him) for the simplicity which comes of the widest generalisations. His row of stately volumes stands alongside the works of Cayley and Sylvester, Adams, Larmor and Tait, and the few other very great mathematicians of our time.

John Aitken of Falkirk also lived to a great age, and was a notable figure of our Society fifty years ago and after. He never took office, and declined even the Presidency (on the ground of age) when it was offered him in after years. The greatest of all discoverers are those who discover the simplest things, and John Aitken was one of these. "Why is one's breath visible on a frosty day" was a question asked, by James Hutton, in one of the first papers ever read before this Society: and Aitken answered it, a hundred years later, in his papers on Dust and Fog and Cloud. How fog and cloud and all the colours of the sunset are due to dust-particles in the air, dust far smaller than the motes in a sunbeam; how and why the colours of the sunset were intensified fifty years ago, after the eruption of Krakatoa; how and why and when the New Moon holds the Old Moon in her arms—these are some of the things that John Aitken explained. He was a fine craftsman and, with an elaborate lathe, made all his instruments and many pretty and delicate things. The ebony ring which holds my dinner-napkin is one of these.

Fifty years ago Professor Turner (not yet Sir William) was one of the Secretaries to our Ordinary Meetings, and in 1908, when Kelvin died, he became by acclamation President of the Society. There is hardly anyone of whom I have so old a memory; for I remember one day, in the year 1867, my uncle rushing into our house, waving his arms, and crying, "Turner's got it!" I told Turner so nearly fifty years after, in the Athenæum. He was extraordinarily delighted; he laughed and chuckled; he made me say it all over again. For that had been the great day of his life, when he was elected to Goodsir's Chair, after a hard fight with Struthers—to the boundless delight of all the younger men.

Turner lived so long that we can all remember him: his sturdy figure, his rapid walk, his little shake of the head, the twinkle of his eye, his dominant personality. He was a trifle pompous, sometimes, and fond of the old verbiage of the anatomists. He came along when I was doing my first day's work in the old dissecting-room. "Well, what have you got?" said he. "An arm, sir," said I, very timidly. "Call it a superior extremity; it's so much more precise!" And so indeed it was, from the point of view of the anatomist. As a demonstrator he was superb. One did not forget one's lesson in a hurry, when Turner had held up nerve or artery in his forceps, and told their names with such a look and voice as though the world depended on them. Of the papers which he read before our Society many were about whales; for he inherited a lifelong interest in these great beasts from Knox and Goodsir, and an insatiable desire to add one after another to his fine collection. Turner had none

of the poetry, scientific imagination or prophetic insight of Goodsir. But there was nothing Turner touched that he did not do with all his might; his love of his subject, his faith and enthusiasm, never flagged for a moment. He was a teacher and a master of men. He fairly won and manifestly deserved the honours that were heaped upon him.

Fifty years and one more year ago, Benjamin Peach was put in charge of the geological survey of the North-West Highlands. Then began a famous chapter in the history of geology, and the unravelling of one of the most difficult regions in the world. As helper and indispensable collaborator he had our future President, his bosom friend, John Horne. It was Peach who first showed the unconformity between the Cambrian rocks and the still older strata; he studied the stupendous thrusts of the great rock-masses of the north-west; and he delighted in the old Cambrian fossils of Durness which his father, coastguardsman at Wick, had been the first to discover. I do not know that Charles Peach, the father, was ever a member of this Society; * but I will not let his name, nor his son's name, pass without paying something of the debt he laid me under. He was a famous naturalist of the old simple school. I and two or three others came under his spell when he was very old and we were boys; and what he taught us, and the love of living things he shared with us, has been worth much to me. What he taught his son was a great deal more. It made him one of the keenest observers, one of the greatest palæontologists and geologists of his time. Both father and son were men of unusual strength and immense vitality; and their great voices and their laughter come down the years.

We had another famous naturalist and palæontologist in Dr Ramsay Traquair; and just fifty years ago some of his best work was being done. He had found a fossil fish on the shore at Wardie when he was a boy, which so fascinated him (as his first ammonite fascinated Hugh Miller), that he never rested till he became the chief student of fossil fishes in the world. It was a delight to listen to one of his papers in this Society, and men came to see rather than to hear. For Traquair was an exquisite draughtsman; he would rapidly sketch a fish upon the board, and fill in, bone by bone and scale by scale, with the accuracy of a Chinese artist, its whole complicated anatomy.

George Chrystal came to Edinburgh five and fifty years ago, welcomed with exuberant delight by Tait and others. He was physicist as well as mathematician. He had been one of the first pupils in the Cavendish, where Maxwell set him to work on Ohm's Law. When he had done,

* Nevertheless he was awarded the Society's Neill Prize, in 1875, for his work on Scottish Zoology and Geology, and for his contributions to Fossil Botany.

Maxwell said that seldom or never had so searching a test been applied to an empirical law; and he added the curious remark that the way it had stood the test encouraged one to believe that the very simplicity of a physical law might be taken as some indication of its exactness! In later years Chrystal became interested in the oscillations or solitary waves on certain lakes, to which, in Switzerland, Forel had given the name of Seiches. Here he found simple experiments and difficult mathematics after his own heart; and the work which he and a certain younger member of this Society did on seiches is as beautiful and as complete an investigation as was ever brought before our Society.

When Chrystal went to Cambridge he found it (as he afterwards said) "almost decadent as an educational institution," at the very time when in Cayley, Stokes, Adams, Maxwell, it had perhaps the greatest galaxy of talent in all its history. Chrystal became an enthusiast for education, striving to do here what the Cavendish Laboratory was doing and had done in Cambridge: giving mathematics a meaning, direction and purpose of which the coach and the examiner had not dreamed. I was in our College Library a day or two ago, and two lads were reading diligently near by. I had the curiosity to look at the books they left behind, and both had been reading Chrystal's *Algebra*. I opened the book at a random page—the chapter was on certain transformations of circular functions; but the interesting thing to me was how Chrystal guided the student, in a few lines, to Riemann on the one hand and Cayley on the other, and then to Maxwell and his lines of force and equipotential, and so to an endless variety of physical problems. Between such algebra, a weapon in the hand of the physicist, and the algebra of the old schoolbooks there is all the difference in the world. Let us not forget Chrystal's kindly, grateful dedication of this truly great book to his old tutor Davie Rennet in Aberdeen: "In memory of happy hours spent in his classroom."

With very tender memories, with a certain peculiar affection, we look back upon Crum Brown. He was one of our Secretaries for a quarter of a century and a member of Council for more than forty years. We have already spoken of him sitting quietly at the table, with his little velvet cap upon his head, keenly alive to everything but speaking seldom. Once indeed he brought down the house, with a sort of magic bottle, which squeaked out vowel sounds in a voice not unlike his own, and in so doing demolished a theory of Fleeming Jenkin's to which the Society had listened a few nights before. We students behaved none too well during his lectures, from which we came across the quadrangle to sit quiet as mice under Tait. But we learned afterwards how fine, how

erudite, how prescient, how suggestive, how educative Crum Brown's lectures had been.

He was a man of very great originality; he was always before his time. When he took his degree, at three-and-twenty, his thesis "On the Theory of Chemical Combination" won no prize, nor was it printed till many years afterwards: but it was a wonderful exposition of structural chemistry, and contained a system of graphic formulæ, undreamed of at the time, to all intents and purposes that which came ultimately into universal use. He first taught in a little extra-mural laboratory of his own in High School Yards, to the smallest of classes. He used to come down to our house and say (in a voice that some of us can still hear), "As I was saying to my man to-day!"—this was his only student. The great John Hunter himself had once no more! But when the University Chair became vacant on Lyon Playfair's retirement, Crum Brown was known to and recommended by Bunsen, Hofmann, Wöhler, Baeyer, Kolbe, Beilstein—in short, by the greatest chemists of the day.

He was a man of insatiable curiosity, interested in what he did not know more even than in what he knew. He wrote a very important paper for our Society on the semicircular canals of the ear and their functions; and illustrated it by curious experiments and exquisite anatomical preparations. He had a passion for making models, geometrical and other; and there were times when the glue-pot was always by his fire and cardboard always ready to his hand. In his old age he wrote on a neglected subject in geometry (as old as Kepler)—the figures generated by producing, again and again, the sides of the regular solids; and when he was very old indeed he lay quietly knitting, and the little mats he knitted were recondite models of interlaced figures and interwoven surfaces. He had both of these hobbies in common with Maxwell. For Maxwell had made some of the same models when he was a schoolboy, and his are in the Cavendish Laboratory to this day; and he once knitted a kettle-holder gayer than the rainbow, for it depicted a square of unannealed glass placed between crossed Nicol's prisms!

Crum Brown was at heart a mathematician. He said that unless the young chemist learns "the imperial language of science," the higher branches of chemistry, which require reason as well as skill, will pass out of his hands.

We come again and for the last time to Tait, and for some of us this feels like coming home. My father and Tait were at Cambridge together and were lifelong friends; and Tait made me welcome, man and boy, to his class and to his home.

I sat in his classroom for the first time wellnigh sixty years ago; and

I remember as if it were yesterday the opening lecture which he gave. It was on the Rainbow and the Aurora; and the moral of it was to show how, of two phenomena, one may have been brought within the knowledge and comprehension of mankind, while the other, no less common nor less beautiful, remains a mysterious pageant beyond our ken. The days went by, and every morning Tait gave us of his best, and all he taught us seemed to be just what we had most wanted to know. We also learned the very important lesson (as Professor Flint long afterwards said) that here was a man whose mind was immeasurably greater than our own.

Tait played with schoolboy zest when it was playtime, and turned easily from work to play. Kelvin said of him that he had made the writing of "T. and T′." a perpetual joke; again in like manner his papers here on Knots were one long game—always with the joke behind it that in four dimensions there would be no knots at all! Even in class, once in a way, when he had drawn a free-hand circle on the board or skilfully thrown a skipping-rope into waves, his eye would meet ours in momentary triumph and schoolboy comradeship. But in fact Tait's life was one of arduous and almost continuous labour; play there might be, but idleness never; and with duty nothing was ever suffered to interfere.

When his Secretaryship of this Society had come, with his lifetime, to an end, the Council drew a Minute, in plain, uneloquent, honest words, to the effect "that they always felt that the affairs of the Society were safe in his hands, that nothing would be forgotten, and that everything would be brought before it at the right time and in the best way."

Clearness of vision and purity of purpose are words that come to one's lips and have been used of him before. He found happiness in the wonder of the world and the simplicity of his home. Until the end drew near, when his natural strength abated and sorrow came at the last, he kept the light heart and the happy laughter of a boy. And we who were his pupils, forty, fifty and sixty years ago, still think of him with love, honour and gratitude; and know by a lifetime's experience how rare, how rare and exceptional, were his qualities of heart and mind.

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XV.—The Structure and Relationships of Lamellibranchs possessing a Cruciform Muscle.

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(With Thirteen Figures.)

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INTRODUCTION.

IN the first decade of the present century Bloomer reported in a series of concise papers (for which see the list of references) the results of his investigations into the structure of the majority of the lamellibranchs which were then classified in the family Solenidæ. In addition to a general description of the external anatomy of these bivalves he paid especial attention to the details of the musculature, to the course of the alimentary canal and the structure of the stomach, while he gave rather generalised accounts of the nervous system and of the arrangement of the circulation, in which he almost entirely followed the previous work of Ménégaux (1890). Bloomer made little attempt to view as a whole the information which had been gathered together as a result of these years of work; the only papers which he published that can be regarded as dealing with his results from a general standpoint being a short one (1903*b*) on the classification of the British species of the genus *Solen*, and a second (1903*c*), equally brief, on the origin and function of the small fourth pallial aperture which

is a marked feature of the anatomy of certain members of the family. This he proved to be a separated portion of the pedal gape, not homologous with the similar structure lying in a more posterior position in some of the Anatinacea and in *Lutraria*.

From the fact that at a period towards the conclusion of his researches into the morphology of the Solenidæ Bloomer published a paper (1911) dealing with the anatomy of the British species of the genus *Psammobia*, it may be inferred that he considered that his previous work led him to a study of the family to which that lamellibranch belongs, and, therefore, that he believed that a relationship existed between these two groups of bivalves, but nowhere does he state any such view.

Ghosh (1920) has collected the data out of Bloomer's papers, and, combining them with a considerable number of observations of his own, made mainly on species from localities in India, has given a systematic account of all the genera included within the family. Influenced, probably, by the later work of Bloomer, he emphasises the relationship between the Solenidæ and the Psammobiidæ. In fact he goes so far as to say that the Solecurtinæ, one of the three subfamilies into which he divides the Solenidæ, "are undoubtedly more related to Psammobiidæ than to the other two subfamilies"—but he still retains them in the Solenidæ! This relationship he bases on the occurrence in certain members of the two groups of a cruciform muscle and of a similar arrangement of the alimentary canal.

Of the animals which are included within the families Solenidæ and Psammobiidæ few have received attention from anyone in addition to the two workers whose results have just been indicated. Neglecting papers of purely physiological or ecological content, it may be noted that Hoffmann (1914) gave a detailed account of the anatomy and histology of *Tagelus dombeyi*, and that Graham (1931) expanded in certain respects the descriptions of *Ensis siliqua* which had been previously published by Bloomer (1901*a*, 1901*b*, 1902*a*, 1902*b*).

In the earlier classifications of the Lamellibranchiata, such as those of Pelseneer (1906) and Ridewood (1903), which were based mainly on the details of the structure of the gills, the Solenidæ and the Psammobiidæ were grouped among the Eulamellibranchiata in the suborder Myacea, in which were also included the Myidæ, the Lutrariidæ, and the Saxicavidæ, along with one or two other less familiar families of bivalves. The relationship between these various molluscs rested on such features as the amount of fusion which the two mantle folds had undergone, the degree of development of the siphons and their retractor muscles, the consequent slight gaping of the two valves of the shell posteriorly, and the well-developed pallial sinus. These characters, however, do not necessarily

indicate any true affinities, but may be interpreted as mainly the results of convergence, due to the fact that the members of this artificial group are burrowing forms, living deep in sand like *Ensis* and *Lutraria*, in mud like *Mya*, or even in limestone like *Saxicava* and *Gastrochæna*. In such environmental conditions muscular siphons are a necessity, giving the animal, deeply buried in sand or rock, access to the food and oxygen in the external waters. Siphons of quite comparable structure may be found in distinct groups, such as the Veneracea and Adesmacea, of similar habits. An extensive fusion of the pallial folds, indicated in such small burrowing lamellibranchs as *Cardium*, marked in large animals such as *Ensis*, *Lutraria*, and some of the Anatinacea, materially assists the maintenance of feeding and respiratory currents in the mantle cavity, which might otherwise become blocked with silt. In some less obvious manner the development of a fourth pallial aperture, in the same animals, is bound up with the same conditions. The Gastrochænidæ, and, to a less extent, the Saxicavidæ, are in the same line as the Pholadidæ and Teredinidæ, which represent the culminating stages in the evolution of the lamellibranchs as burrowing or boring animals, and which, in this classification, are united in a special suborder of their own, the Adesmacea.

The main character of which Bloomer and Ghosh both make use as the basis for their approximation of the Solenidæ and the Psammobiidæ is one which is encountered in no other family of the suborder, the possession of a cruciform muscle. This, however, as shown by Graham (1934), is a feature shared with these two families by most of the members of a quite distinct suborder in the classification of Pelseneer, the Tellinacea. In this are included three families—the Tellinidæ, Scrobiculariidæ, and Donacidæ—the members of which all possess a cruciform muscle, and a fourth, the Mactridæ, in which there is no trace of it.

This classification of the Lamellibranchiata, therefore, leads to an obviously unsound position, in which a few members of two distinct suborders possess an elaborate sensory apparatus, the like of which is to be discovered in no other bivalve, and the development of which cannot possibly be due to convergence.

To avoid this difficulty it is necessary to have recourse to a classification which depends, not on gill structure, but on variation in the structure and arrangement of the hinge teeth of the shell, based on the embryological work of Bernard (1898) and modified recently by Thiele (1926). Such a classification gives a more reasonable arrangement of the groups of bivalves which are under consideration: the Solenidæ, Tellinidæ, Semelidæ (=Scrobiculariidæ), Psammobiidæ, and the Donacidæ have now been all united into a single suborder, the Hemidapedonta, whereas the Mactridæ,

in which the Lutrariidæ have been merged, fall alongside the Myidæ, Saxicavidæ, Pholadidæ, and Teredinidæ in the suborder Desmodonta. Those bivalves which possess a cruciform muscle are in the former suborder: those which are without it are in the latter.

This revised classification, however, whilst removing the more glaring misplacements of the earlier, carries the difficulty a stage further. Thiele divides the Hemidapedonta into two tribes, the first the Tellinacea, in which are gathered all the families except the Solenidæ, the second the Solenacea, comprising that family alone. As has been shown elsewhere (Graham, 1934) the musculus cruciformis occurs in certain members of the Solenidæ only, and, on that basis, the family was split into two: (1) the Solecurtidæ, which possess a cruciform muscle; (2) the Solenidæ, without a cruciform muscle. The question of the relationship of the Solecurtidæ to the Tellinacea now arises, and it is the purpose of this paper to consider that, and to suggest that the Solecurtidæ be even further removed from the Solenidæ than the position of a separate family indicates, and that they be placed in the Tellinacea, where occur all the other genera with the cruciform muscle.

To answer this question an anatomical investigation of the following lamellibranchs was undertaken: *Gari tellinella*, *Donax vittatus*, *Solecurtus scopula*, *Cultellus pellucidus*, while special points in the anatomy of *Macoma balthica*, *Tellina crassa*, *Solecurtus chamasolen*, and *Scrobicularia plana* were also investigated. The nomenclature of these animals is that given by Winckworth (1932). The material used came mostly from the Plymouth Marine Laboratory, but I have to thank Mr R. Bassindale of the Mersey Investigation for specimens of *Macoma* sent from Liverpool, whilst some of the specimens of *Donax* were collected from the Firth of Forth, where they are locally very abundant. The bivalves were fixed either in Bouin's fluid or in Helly's modification of Zenker's fixative. Sections, cut 8 μ thick, were stained, some with Delafield's hæmatoxylin and eosin, some with Heidenhain's azan stain. Reconstruction from these sections was made by the graphic method. Dissections of each species were made under the binocular microscope.

Gari tellinella.

This mollusc, as being less well known than the others, has been selected for a full description with which comparison of the others may be made.

The animal is laterally compressed and has a narrow ventral surface; viewed from the side it has the shape of an elongated oval, the anteroposterior axis measuring rather more than twice the distance from the

ventral edge to the dorsal surface. The anterior half of the animal is usually slightly deeper and less pointed than the posterior, the ligament lying near the mid-point of the dorsal surface, on the posterior side. A typical specimen is 24×10 millimetres.

The two mantle folds are completely separated from each other from the anterior adductor to the cruciform muscle, leaving therefore, over the whole of the anterior end of the bivalve and the greater part of its ventral surface a large pedal gape through which the foot may be protruded. Along the edge of each fold runs an inner longitudinal fold or velum, and small tentacles are also present. Over the dorsal side of the anterior third of the anterior adductor muscle these inner longitudinal folds are fused, the rest of the mantle edges remaining separate; behind that point both fuse completely, save for a median periostracal groove, the edges of which are fringed by minute tentacles, stretching along the whole length of the mid-dorsal line of the animal. A similar fusion of the vela occurs at the cruciform muscle, where they unite with the walls of the two siphons, which are properly regarded as outgrowths of the united folds, and their apertures as persistent remains of the original cleft between the mantle halves. At the posterior end of the animal the rest of the mantle edges remain separate, while the siphons have retreated away from them in an anterior direction, so that they now arise a considerable distance from the true posterior end. There is thus formed, as a result of this migration of the base of the siphons, a large cavity, wholly enclosed within mantle folds, which may be referred to as the siphonal space, into which the two siphons may be entirely retracted.

The siphons are completely separate from one another and are of considerable length when extended. The apertures are slightly, but irregularly, lobed, while along each siphon run three rows of small tentacles which mark the course of underlying nerves. The walls of the tubes are muscular, the fibres being arranged in no fewer than six layers of circular and longitudinal muscles. The direction of the fibres, from outside inwards, is longitudinal, circular, longitudinal, circular, longitudinal, and again longitudinal. Those longitudinal layers which underlie the bounding epithelia are extremely thin, but the inner layers attain a considerable thickness; it is these, in point of fact, which form the main retractor muscles of the siphons, spreading out fanwise at their anterior ends to be inserted on the valves of the shell. In addition to these sets of muscles transverse fibres run from the basement membrane of one epithelium to that of the other.

The siphonal muscles are innervated by special nerves from the visceral ganglia (fig. 3, *d.s.d.*, *d.s.v.*, *r.s.*, *v.s.*).

Parallel with the edge of the mantle runs the insertion of the orbicular muscle on the shell. The fibres which pass from this to the pallial margin diverge into two principal sets: one, passing median to the circumpallial nerve, supplies the more median portion, ending in the neighbourhood of the periostracal groove; the other, passing lateral to the nerve, is connected with the most lateral part of the mantle edge, immediately underlying the shell. In addition to these portions of the orbicular muscle there are fibres running transversely across the mantle into the inner longitudinal fold, of which they act as retractors, and delicate longitudinal fibres lie immediately within the epithelium of the ventral and the lateral surfaces, and also more deeply embedded in the connective tissue near the base of the velum and around the tentacles.

The mantle groove passing along the mid-dorsal line of the mollusc is also equipped with muscle fibres, most of which are retractor fibrillæ running from the fringing tentacles ; a few, however, are longitudinal fibres running below the epithelium.

The anterior adductor muscle (fig. 1, *a.a.*) lies well forward, its posterior end dorsal to the mouth. It is oval in section anteriorly, with its edge parallel to that of the shell, and somewhat squarish at the posterior end, while the ventral surface is convex. The posterior adductor (*p.a.*) is, in lateral view, almost exactly circular.

The foot is axe-shaped, the ventral edge being narrow, without a flattened sole. At the posterior end may usually be distinguished a small slit-like opening, the aperture of the duct of the byssus gland. The upper, visceral portion of the foot, like the remainder of the surface of the bivalve, is smooth externally, and is covered with a low, non-ciliated epithelium; the ventral, muscular part is ridged with fine elevations and valleys, and is covered with a ciliated epithelium below which many mucous cells lie in the connective tissue among the superficial layers of muscle. These are absent from the visceral part. At the anterior extremity of the foot, where that organ is free from the body of the mollusc, the ciliated covering spreads over the whole surface.

The musculature of the foot deserves fuller treatment, as it has been used as a character of systematic value by Bloomer and Ghosh. Both these authors speak, when dealing with the arrangement of the muscles in this portion of the animal, as if there were two distinct sets of approximately equal importance. To one of these they give the name "intrinsic muscles of the foot" and describe as such various sets of circular, longitudinal, and transverse muscles; for the other set the term "extrinsic muscles of the foot" is employed, and in this are included such pedal muscles as are inserted on the valves of the shell. A study of the papers of these authors

leaves the undoubted impression that there are two completely independent sets of muscles. But if the course of the so-called extrinsic muscles is followed from their insertion on the shell into the foot, it is discovered that the intrinsic muscles, in practically every instance, are nothing more than those portions of the extrinsic muscles which happen to lie within the foot. If all which can be shown to be merely the pedal ends of the extrinsic musculature are removed from the collection of intrinsic muscles, the number of intrinsic muscles proper—that is, those which never emerge from the foot—is reduced to a very small number indeed, which are restricted to its more distal portion. In particular, those muscles which have been referred to by previous writers as the principal longitudinal muscles of the foot, are the pedal ends of extrinsic muscles.

The extrinsic musculature of the foot of *Gari tellinella* consists of the retractor pedis anterior, the retractor pedis posterior, and the protractor pedis on each side. Bloomer (1911) mentions and figures what he calls an elevator pedis muscle, but although I have made a careful search, I have been unable to find anything corresponding with it either in sections or by dissection, and am therefore driven to conclude that such a muscle is not present in this species, although from Bloomer's figure it appears to occur, albeit rather poorly developed, in *Psammobia vespertina* (*Gari depressa* in Winckworth, 1932).

The arrangement of the muscles is shown in fig. 1.

The protractor pedis muscle (*p.p.*) is inserted on each side on the ventral surface of the anterior adductor. Thence it passes backwards, keeping very close to the shell, and turns ventrally into the foot, where it is split into two sheets of fibres separated one from the other by a thin layer of circular muscle (*c.m.*). The outer of the two sheets lies just within the pedal epithelium, and therefore probably corresponds with what Bloomer called the pedal integument. In both layers the trend of the constituent fibres is backwards and downwards, but from their point of entrance to the foot at the anterior dorsal corner they spread out fanwise so as to cover the greater part of its surface. The muscle is supplied by a small twig from the statocyst nerve (fig. 4, *p.p.n.*). That, in its turn, is a branch of the cerebro-pedal connective, which it leaves at a point just anterior to where the connective enters the pedal ganglia. Whether the nerve fibres to the protractor pedis muscle have an origin in the cerebropleural ganglion, such as those to the statocyst have been shown to possess, cannot be stated.

The retractor pedis anterior muscle (*r.p.a.*) is inserted on to each valve by a triangular insertion adjoining the posterior end of that of the anterior adductor, with the base of the triangle dorsal. Thence the fibres pass almost straight ventrally and the muscles of each side fuse so as to form a

thick median bundle which immediately splits again into two halves, one right and one left, passing deep into the ventral portion of the foot. These halves are the most internal of all the muscles of the foot and consist of fibres running mainly ventrally and forwards, a few, however, running posteriorly. The nerve supply is from two pairs of nerves originating from the pedal ganglia (fig. 4, *r.p.n.* 1, 2).

The last of the extrinsic muscles of the foot are the posterior retractors (*r.p.p.*). Each of these is inserted on the shell by a small oval insertion lying dorsal and anterior to that of the posterior adductor. Like the anterior retractor, the two muscles pass ventrally towards the middle line,

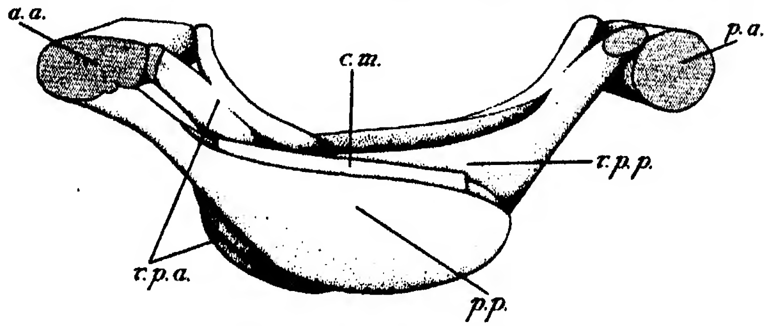

FIG. 1.—*Gari tellinella.* Diagram of the arrangement of the muscles. *a.a.*: anterior adductor; *c.m.*: layer of circular muscle; *p.a.*: posterior adductor; *p.p.*: protractor pedis; *r.p.a.*: anterior retractor pedis; *r.p.p.*: posterior retractor pedis. × 4½.

join, and then diverge to reform right and left muscles. These pass in an antero-ventral direction into the foot, lying between the inner sheet of the protractor pedis on the outside and the anterior retractor on the median aspect. In the ventral part of the foot this layer is split into an inner and an outer by the intercalation of a layer of obliquely directed fibres which extends the whole length of the foot and forms a large number of strands crossing from one side to the other. The innervation of the posterior retractors is identical with that of the anterior retractors.

In addition to these muscles the visceral part of the foot contains a large number of small, isolated bundles of transverse muscle fibres which pass between the coils of the intestine. Along with the sheet of circular fibres which divides the protractor pedis muscle into two sheets, and the oblique fibres which divide the posterior retractor, these are the true intrinsic pedal muscles.

The gills hang on either side into the pallial cavity from the ctenidial axis. This begins in a rather high, dorsal position on the visceral mass and runs downwards and backwards to come to an end on the partition which separates the inhalent from the exhalent siphon.

The inner demibranch is approximately diamond-shaped, and the filaments of which it is composed arise from the axis and run downwards and forwards, parallel to the anterior, dorsal side of the diamond. The anterior filaments are longest, the length of the others gradually decreasing the nearer they lie to the posterior end. The most anterior filament of all is fused along the whole of its anterior side to the visceral mass, and its ventral end lies between the two palps. While running alongside the foot the ascending lamellæ of the inner demibranchs are attached to it by cilia; behind the foot they are joined to each other in the same manner.

The outer demibranch, arising from the same length of ctenidial axis, is triangular in outline, with the result that it overlies only the posterior half of the inner, leaving the anterior triangle of the diamond exposed. The filaments have the same downward and anterior trend as in the other gill, with the result that, in this case, the longest ones arise from the middle of the axis and run to the apex of the triangle, those at the ends being shorter. The ascending lamellæ of the outer demibranchs are continued above the level of the ctenidial axis as a supra-axial extension which fuses by means of ciliary junctions with the body of the bivalve near the most dorsal limit of the pallial cavity.

The gills are heterorhabdic with broad principal filaments lying at the bottom of rather shallow folds, each with a wide groove running along its outer face (Ridewood, 1903). The most anterior part of each outer demibranch is not folded.

The labial palps are moderately large; each has the shape of an equilateral triangle, and bears about a dozen folds.

The mouth lies between the palps ventral to the anterior adductor muscle. A narrow œsophagus (fig. 2, *o.*) of considerable length—equal to about one-fifth of the total length of the mollusc—passes between the two anterior retractor muscles, dorsal to their point of union, towards the stomach, which lies surrounded by the tubules of the digestive diverticula. In shape the stomach (*st.*) is rather elongated and dorso-ventrally flattened. Projecting into the lumen from the left wall are two ridges—a large longitudinal ridge of connective tissue, erroneously called a "muscular papilla" by Bloomer, which serves as a support for the greater part of the gastric shield, and a smaller, horseshoe-shaped ridge which lies ventral to the other, with the convexity of the curve directed forwards. The right side of the stomach has no such prominent features, but the lining epithelium presents a large number of delicate longitudinal folds.

At the posterior end of the stomach the style-sac (*s.s.*) and the intestine (*i*) take origin together from the ventral side. The two tubes are in open communication, the two typhlosoles, major and minor, forming ridges

which tend to separate the one from the other; they may be easily distinguished by the much larger diameter of the style-sac and by the very definite and well-known histological characters of its lining epithelium. The two conjoined portions of the gut take a ventral and posterior course which leads them into the most ventral part of the foot where the style-sac terminates rather abruptly, and the intestine, separating from it, bends

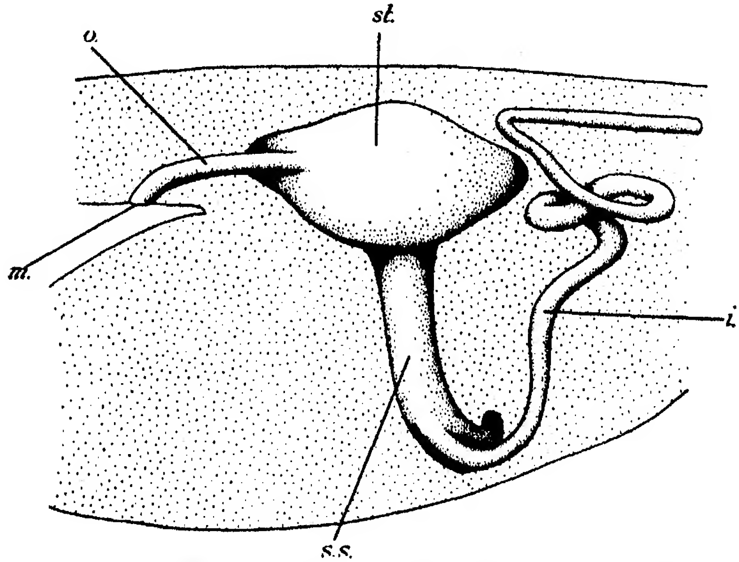

FIG. 2.—*Gari tellinella.* Diagram of the course of the alimentary canal. *i.*: intestine; *m.*: mouth; *o.*: œsophagus; *s.s.*: joined style-sac and intestine; *st.*: stomach. × 6.

back on itself and, exhibiting two or three closely packed coils, passes along the dorsal or posterior aspect of the sac towards the hinder-end of the stomach. When it reaches a position dorsal to the posterior end of the stomach it turns sharply backwards and thence follows the usual course through the ventricle and over the posterior adductor muscle to the anus.

The digestive diverticula spread all around the stomach and into the visceral portion of the foot, but do not extend dorsal to the anterior adductor. Three ducts lead from the stomach: one, anteriorly, on the right; one from the middle of the ventral surface; the third on the left, posteriorly.

The nervous system of *Gari* is built on the usual lamellibranch plan—three pairs of ganglia united by connectives. Its principal tracts are most easily shown by means of a diagram (see fig. 3), but there are one or two points to which attention may be directed.

From each cerebropleural ganglion (*cp.g.*), which lies in its typical position by the mouth, pass five nerves. Anteriorly the anterior pallial

nerve (*a.p.*) supplies the mantle, passing right round its edge as a circum-pallial nerve (*cp.*) which joins posteriorly with the visceral ganglion. A branch from the anterior pallial (*d.p.*) passes to the median dorsal pallial groove, and a ramus of this innervates the anterior adductor muscle. The visceral and pedal connectives arise posteriorly. The fourth nerve

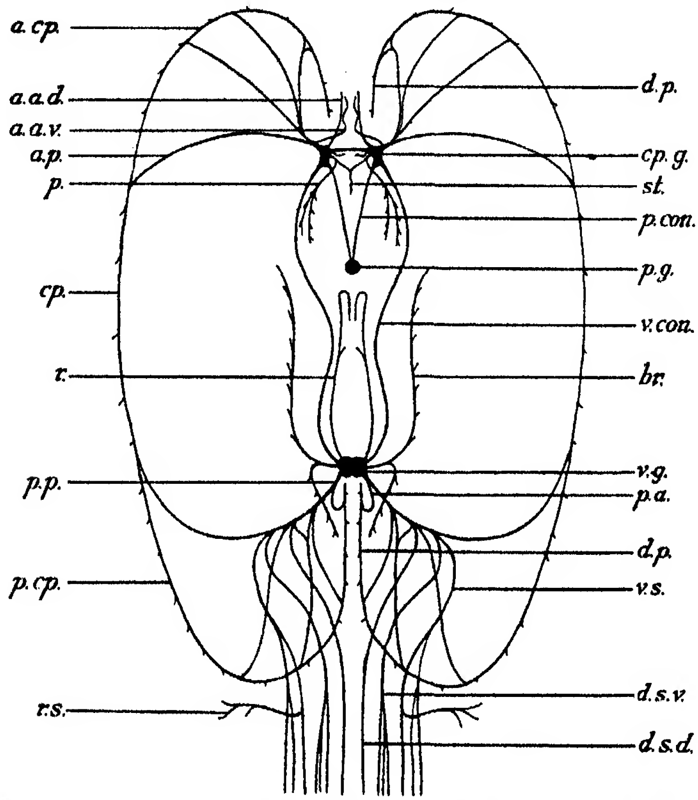

FIG. 3.—*Gari tellinella.* Diagram of the nervous system. *a.a.d.*: dorsal nerve to anterior adductor; *a.a.v.*: ventral nerve to anterior adductor; *a.cp.*: anterior circum-pallial nerve; *a.p.*: anterior pallial nerve; *br.*: branchial nerve; *cp.*: circumpallial nerve; *cp.g.*: cerebropleural ganglion; *d.p.*: dorsal pallial nerve; *d.s.d.*: dorsal nerve to dorsal siphon; *d.s.v.*: ventral nerve to dorsal siphon; *p.*: nerve to palp; *p.a.*: nerve to posterior adductor; *p.con.*: pedal connective; *p.cp.*: posterior circumpallial nerve; *p.g.*: pedal ganglion; *p.p.*: posterior pallial nerve; *r.*: renal nerve, possibly also supplying the heart; *r.s.*: nerve to retractor siphonis muscles; *st.*: stomatogastric nerve; *v.con.*: visceral connective; *v.g.*: visceral ganglion; *v.s.*: nerve to ventral siphon. For the nerves arising from the pedal ganglion, see fig. 4. × about 3½.

is that to the palp (*p.*), which leaves the ganglion close to the base of the cerebropleural connective, runs along the base of the palps and gives small branches to the mouth and œsophageal region which form a slender subœsophageal commissure (*st.*).

The pedal ganglia (fig. 3, *p.g.* and fig. 4) give origin to four pairs of

nerves, two anteriorly and two from the posterior side, of which one pair curves sharply forward. Of the anterior nerves, one pair forms the cerebropedal connectives from each of which pass branches to the enclosed statocysts and the protractor pedis muscles, while a posterior twig runs to those transverse intrinsic muscles which lie among the viscera. The second anterior pair of nerves, along with the two posterior pairs, supply the retractor and other muscles of the foot.

The two visceral ganglia (fig. 3, *v.g.*), which are closely apposed, lie below the posterior adductor muscle. Ventrally a pair of eminences marks the position of the osphradial ganglion at the base of each branchial nerve. On the dorsal surface there are four lobes, two small anterior ones which rise only slightly above the general surface of the ganglion, and two salient posterior lobes forming small spheres outstanding above the rest of the ganglion. From each ganglion five nerves arise. From the dorsal side, anteriorly, arises the cerebrovisceral connective. Posteriorly two nerves leave: one, a large posterior pallial nerve (*p.p.*) which completes the circumpallial nerve and also gives rise to two nerves passing to the exhalent siphon (*d.s.d.*, *d.s.v.*) and to two others innervating the inhalent siphon (*v.s.*) and the retractor muscles of the siphons (*r.s.*). The other, which leaves the ganglion very close to the first, is the nerve to the posterior adductor muscle (*p.a.*) through which it passes, emerging dorsally to join that part of the circumpallial system which runs in the mid-dorsal groove. Anteriorly, from the ventral surface the branchial nerve (*br.*)

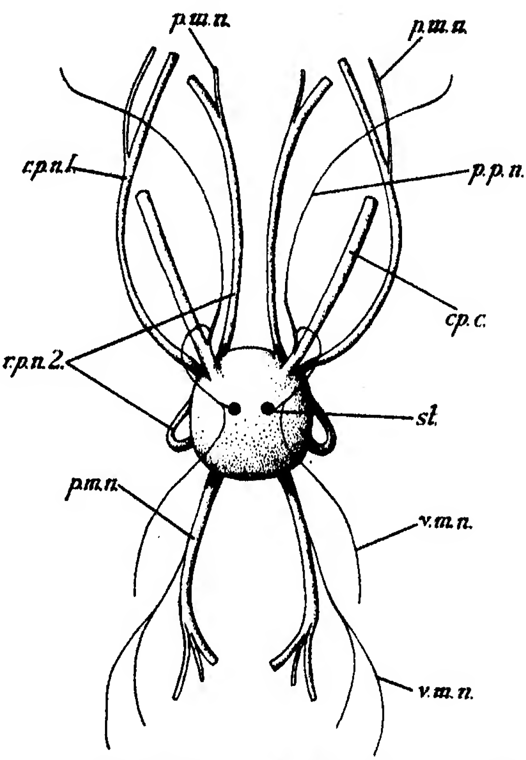

FIG. 4.—*Gari tellinella.* Reconstruction of the pedal ganglion and the nerves arising therefrom. *cp.c.*: cerebropedal connective; *p.m.n.*: nerves to intrinsic pedal muscles in ventral part of foot; *p.p.n.*: nerve to protractor pedis muscle; *r.p.n.* 1, 2: nerves to retractor pedis muscles; *st.*: statocyst; *v.m.n.*: nerves to intrinsic pedal muscles in dorsal part of foot. × about 15.

enters the ctenidial axis and a small nerve (*r.*) runs forward in the ventral body-wall to the kidney, passing external to its aperture. Of the exact destination of this nerve I am doubtful, as it is very small and difficult to follow. It may be traced with certainty as far forward as the anterior end of the pericardium, along the floor of which it passes. There it turns dorsally to the upper side of the pericardial chamber where, embedded in connective tissue, it runs backward once again. Whether this is purely a renal nerve, or one which is also supplying the heart, is a question to which I am not able to give a definite answer. It is relevant to add at this point that no other nerve has been traced to the heart in *Gari*, and that Carlson (1905) found recurrent cardiac nerves from the visceral ganglia in several other lamellibranchs.

The right and left excretory organs are united by a broad passage which puts their cavities in free communication.

Tellina crassa.

This species of the genus grows to a fairly large size, typical specimens being about 40×35 millimetres. They are oval in outline with a slight twist in the margin of the shell near where the siphons can be protruded. The ligament lies near the middle point of the dorsal side on the hinder half of each valve.

The pallial structure and fusions are as in *Gari*.

The siphons are long and separate and have no longitudinal rows of tentacles, though a few occur around the margin of the aperture. The arrangement of their musculature is exactly similar to that which has been already described and the central layers of longitudinal muscles form well-developed retractors.

The foot is large and axe-shaped. Protractor pedis muscles are present, attached to the shell below the squarish insertion of the anterior adductor muscle and passing back superficially over the foot. The fibres of the posterior retractors form the next layer, running forwards from oval insertions adjacent to those of the posterior adductor. The innermost layer of all consists of strands of the anterior retractors which are inserted to each valve by triangular insertions, the base uppermost, just posterior to those of the anterior adductor. There are no elevator pedis muscles. A byssus gland is present.

The ctenidial axis arises in a dorsal position on the visceral mass and runs diagonally backwards and downwards to the inner ends of the siphons. The outer demibranch is triangular in outline and is very little folded; it lies entirely dorsal to the ctenidial axis and its ascending lamella (which, because of this inversion of position, has actually the opposite

direction) is joined to the body-wall overlying the pericardium and excretory organ. The inner demibranch is lozenge-shaped and lies entirely ventral to the gill axis; it is thrown into much deeper folds than the other. The ascending lamellæ of this gill are joined either to the visceral body-wall or to each other.

The palps are large, their length being slightly greater than one-third of the total body-length. They possess each about twenty-eight folds.

The rather short œsophagus (fig. 5, *o.*) which is equal to about one-sixth of the total body-length, leads back between the anterior retractors

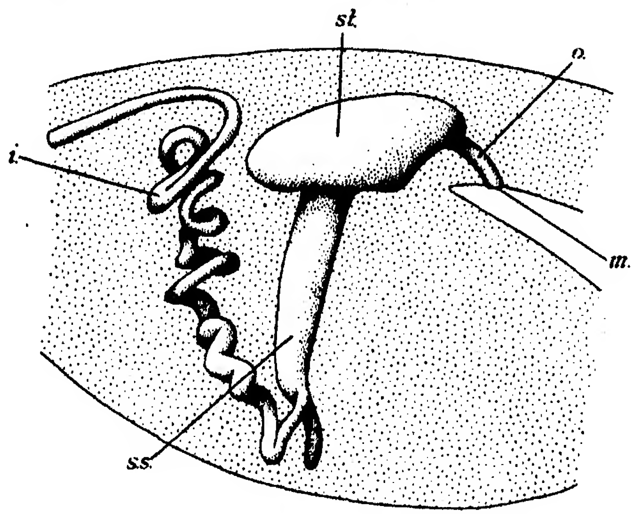

FIG. 5.—*Tellina crassa.* Diagram of the course of the alimentary canal. For lettering, see fig. 2. × 3.

to enter the stomach (*st.*) on the left side a little behind the anterior end. The stomach is rather flattened from above downwards and has the customary internal papilla on its left side for the support of the gastric shield. The style-sac and intestine (*s.s.*) leave the stomach together from the middle of the ventral surface and pass ventrally and slightly backwards towards the ventral limit of the foot. There they separate, and the intestine (*i.*) leads dorsally, coiled in a rather irregular spiral fashion, to the anterior end of the pericardium through which it passes back to the anus.

Macoma balthica.

Of almost the same shape as *Tellina crassa* this little bivalve is only 16 × 12 millimetres.

The structure of the mantle and of the siphons is as in *Tellina crassa.* The anterior adductor is a large, rather elongated muscle, the posterior

oval, and somewhat drawn out to an edge along its ventral surface. Into the axe-shaped foot run, from the anterior end, a weakly developed protractor muscle and an anterior retractor on each side, the latter fastened to the shell by a single insertion lying separated by a short gap from that of the adductor. From the posterior end enters the retractor pedis posterior on each side. There is a small byssus gland.

The arrangement of the demibranchs is as in *Tellina crassa*; they differ in that neither inner nor outer has a folded surface.

The palps are large, their length being equal to about one-third of the total length of the mollusc, and bear between thirty-five and forty folds.

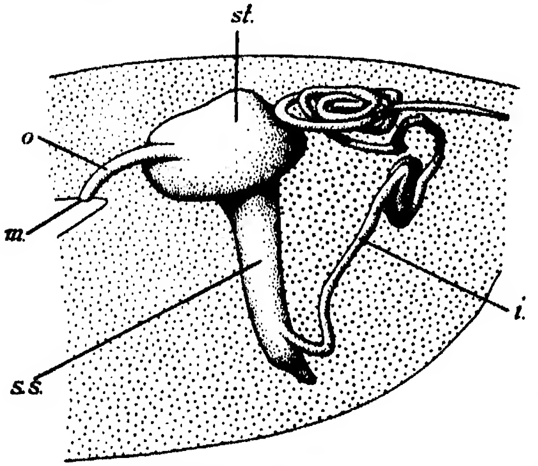

FIG. 6.—*Macoma balthica.* Diagram of the course of the alimentary canal. For lettering, see fig. 2. × 6.

The œsophagus (fig. 6, *o.*) is short (about one-sixth of the animal's length) and leads to an approximately spherical stomach (*st.*). The style-sac and intestine (*s.s.*) pass down the foot as a single structure from the ventral surface of the stomach. In the ventral region of the foot the two separate and the intestine (*i.*) passes up to the posterior end of the stomach and winds itself into a close counter-clockwise spiral of two turns in the transverse plane, then, passing still more close to the dorsal surface, it coils into a similar tightly packed spiral of two turns lying in the horizontal plane, reverses its direction, twists once round the collection of coils in this new sense into the mid-dorsal line and thence crosses the spiral into the pericardium.

Scrobicularia plana.

Scrobicularia is similar in size and shape and in the arrangement of the pallium to *Tellina crassa*. The two siphons are well developed, long, and separate, each with a fringe of tentacles around the orifice.

The anterior adductor is a large muscle elongated in section to a considerable extent; the posterior adductor is also well developed, and is oval in section.

The foot is axe-shaped, with no sole, and possesses a small byssus gland. The protractor pedis on either side is weakly developed and is

superficial in position in its course over the foot. Beneath its fibres runs a layer belonging to the posterior retractor which is attached to the shell by a small triangular insertion in the typical position. In the innermost parts of the foot run bundles of fibres belonging to the anterior retractors which have each a single head inserted close behind the anterior adductor.

The gills have a very similar disposition to that in *Tellina*, the outer demibranch extending dorsal to the ctenidial axis to leave the inner uncovered. The former consists of direct lamella only.

The palps are long, about one-quarter of the total length of the bivalve, each with about thirty folds.

The mouth (fig. 7, *m.*) leads by the œsophagus (*o.*) to the slightly

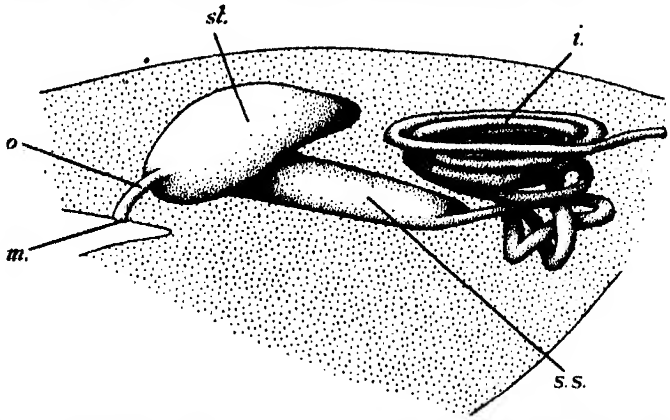

FIG. 7.—*Scrobicularia plana.* Diagram of the course of the alimentary canal. For lettering, see fig. 2. × 3.

elongated stomach (*st.*). From the ventral side of this the united intestine and style-sac (*s.s.*) pass backwards, but only a little ventrally, into the foot. Leaving the style-sac at its lower extremity the intestine (*i.*) coils upwards in an irregular, loose manner, then passes into a regularly arranged, tightly packed, double spiral coil which lies in the horizontal plane just behind the posterior end of the stomach. The first two turns of the spiral, those proximal to the stomach, are in a clockwise direction when seen in dorsal view, then the sense of the spiral reverses, and there follow two circles in the opposite direction. At the end of these the intestine turns back on itself and passes straight from the anterior end of the spiral backwards to enter the pericardium.

Donax vittatus.

This species is, superficially, very like *Gari tellinella* in shape and size, about 25 × 12 millimetres, but on a close examination it is found that whereas the hinge and the ligament lie nearer the anterior end in the

latter lamellibranch, they lie closer to the posterior end in the case of *Donax*, with the result that it is the anterior half which contributes more to the bulk of the animal.

The mantle is arranged similarly to that of *Gari*, there being a large pedal gape from the anterior adductor to the cruciform muscle, and behind that a large siphonal space. The siphons are separate, but are relatively shorter than those of the forms already described, and have a considerably greater development of muscular tissue due to an increase of the

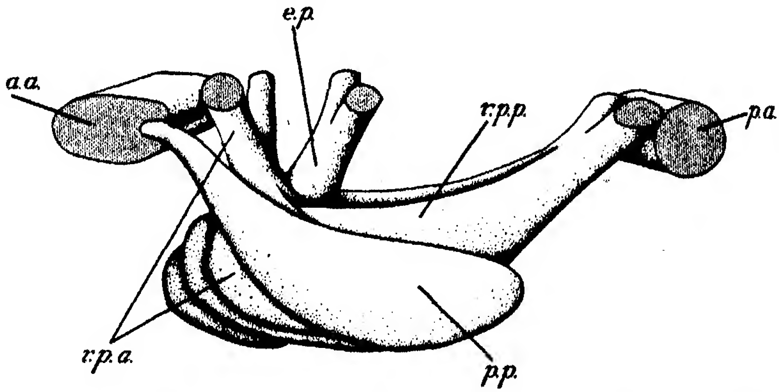

FIG. 8.—*Donax vittatus*. Diagram of the arrangement of the muscles. *e.p.*: elevator pedis muscle. Other letters as in fig. 1. × 4½.

thickness of the inner layers of longitudinal muscles. Immediately below the epithelium covering the siphons of *Donax* is a layer of circular muscles, which is either absent or else so poorly developed as to be easily overlooked in *Gari*.

The anterior adductor is roughly oval in cross-section, but the posterior surface is indented by a deep groove passing from one side to the other; into this pass certain fibres of the protractor pedis muscles. This adductor lies wholly in front of the mouth. The posterior adductor is oval in section.

The foot is axe-shaped and has no flattened sole. There is no byssus gland. The musculature differs from that of *Gari* in that a pair of elevator pedis muscles are retained (fig. 8, *e.p.*) and in a few other points of detail. The most external muscular coat of the foot belongs to the protractor muscles; these pass up towards the anterior adductor and are inserted either on the ventral surface of that muscle or on the parts bordering the transverse groove. The retractor pedis anterior (*r.p.a.*) consists of two sheets separated one from the other by part of the retractor pedis posterior. Of these, one lies immediately within the layer of the protractor pedis, and obviously corresponds to a thin sheet of more or less

circular fibres (see fig. 1, *c.m.*) which occurred in that situation in *Gari tellinella*, but which I was unable to trace into any definite union with any other muscle. In the genus *Donax*, however, the union is quite apparent. The second half of the muscle lies more deeply in the foot.

The retractor pedis posterior is also split in the ventral region of the foot into two portions, in exactly the same manner as already described, by muscles belonging to the intrinsic system.

The two elevator muscles form the most internal of all the pedal muscles. They are inserted on the valves of the shell close to the hinge, near the anterior end of the pericardium, whence they pass directly downwards into the foot. Like the posterior retractor muscles they fuse together to form a median muscle between their points of insertion on the shell and the foot, within which they separate again.

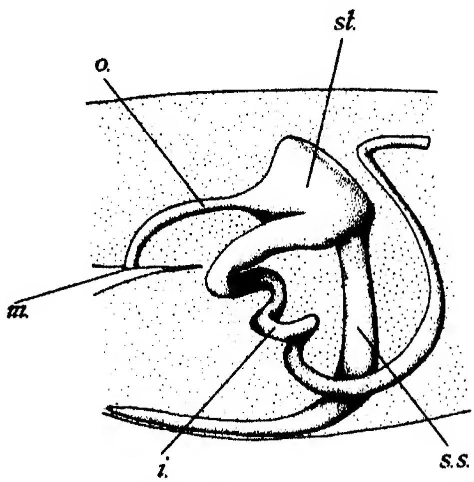

FIG. 9.—*Donax vittatus.* Diagram of the course of the alimentary canal. For lettering, see fig. 2, except that here *s.s.*: style-sac separate from intestine. × $4\frac{1}{2}$.

The arrangement of the gills is as in *Gari tellinella*. They are, however, homorhabdic, and are not flung into folds. There is a lack of both interlamellar and interfilamentar tissue connections, so that the gills, in sections, have almost the appearance of a filibranch type.

The palps are small, with about fourteen or fifteen folds on the folded surface, and are equal to about one-sixth of the total body-length.

The mouth (fig. 9, *m.*) leads into a fairly long œsophagus (*o.*) which passes backwards into the stomach, which is short and high in shape. At the posterior end of the ventral surface the stomach merges into the style-sac (*s.s.*) which passes to the lower side of the foot, there curving forward and running anteriorly to a point just in front of the level of the mouth, lying in the middle line of the foot close to the surface.

The intestine (*i.*) arises from the middle of the ventral surface of the stomach on the left side by an aperture which is quite distinct from that of the style-sac. It passes forward and curves ventrally into the foot and exhibits two or three loosely arranged coils in its downward passage. On reaching the point where the style-sac bends to pass anteriorly the intestine runs to the posterior side of the sac, passing on its left side, and then

moves upwards to the hinder-end of the stomach, its course being without coils. The remainder of the alimentary tract has its usual course through the heart to the anus.

Cultellus pellucidus.

This animal is distinct in shape from any which has been so far described: it is elongated and roughly rectangular in outline, although the anterior end curves slightly dorsally so as to fling the ventral margin into a slightly arcuate form. An average sized specimen measures 15×5 millimetres, so that the length is considerably greater than the breadth. The hinge and ligament lie very close to the anterior end so that the discrepancy between the lengths of the anterior and posterior sides of the valves which is indicated in *Tellina* and *Donax* is here much more pronounced.

The mantle folds are separate from each other from the anterior end of the anterior adductor muscle, along the short anterior end and along a portion of the ventral surface equal to about one quarter of its total length. Behind this point they are completely fused together except for the two siphonal apertures. Anterior to this point where fusion takes place there lies a small gap, fringed with tentacles, which is the so-called fourth pallial aperture, lying just ventral to the tip of the foot when that organ is in the retracted position. Between the anterior end of this aperture and the anterior end of the bivalve itself is a region where the amount of fusion of the edges of the mantle folds is variable: occasionally specimens are encountered in which this region gapes widely, but normally the edges are closely adpressed; it will be noted that this is mere contiguity: there is no real tissue connection. The fourth aperture is therefore continuous with the rest of the pedal gape. That part of the margin of each pallial fold which lies at the extreme anterior end of the animal is inflected, bearing a medianly directed extension, called by Bloomer a "pedal valve," acting as a mechanism for sealing the aperture when the foot is withdrawn into the mantle cavity.

In the arrangement of the muscles of the pallial margin there is a resemblance to *Gari* and the other examples already described in those portions of the mantle where there is no fusion of the edges. Where that fusion has taken place there is a corresponding modification of the arrangement of the orbicular fibres. From its insertion on the shell only one layer of muscle fibres passes to the pallial edge, passing laterally to the circumpallial nerve, and supplying all parts. Longitudinal fibres are much reduced in number and form a few fine strands below the basement membrane of the epithelium. The most conspicuous muscles of the

united portions of the mantle edge, however, are transverse in direction, passing from one side to the other just ventral to the grooves along which waste matter is being transported back to the base of the ventral siphon.

The two siphons are separate, but are exceedingly short and terminal in position; that is to say, there is no siphonal space into which they can be retracted. Each bears a fringe of rather long tentacles at the extremity. In accordance with their much smaller size their retractor muscles are feebly developed and form an inconspicuous tuft of fibres inserted on each valve. The muscle layers within the wall of each siphon are much less numerous and extensive than in *Gari tellinella*; their order,

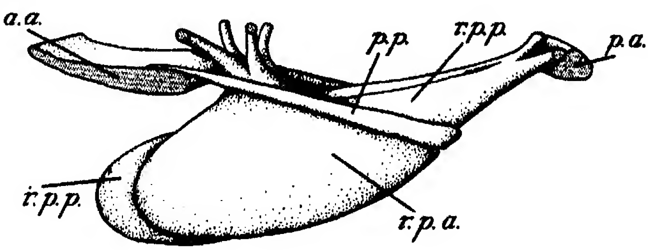

FIG. 10.—*Cultellus pellucidus*. Diagram of the arrangement of the muscles. For lettering, see fig. 1. × 7½.

from outside inwards, is longitudinal, circular, longitudinal, and it is the two external sheets of longitudinal muscles which join together at the base to form the retractors. A further point of divergence is the much more compact structure of the walls. The muscle layers are more securely padded with connective tissue and the blood lacunæ are less numerous.

The anterior adductor (fig. 10, *a.a.*) is a narrow, elongated muscle, slightly tapering at the anterior end, and slightly curved upwards. The posterior adductor is of moderate size, approximately oval in section, somewhat pointed behind.

The foot is stout, and rather short and deep. The anterior end is obliquely truncated but does not form a sole to any marked extent. There is no byssus gland.

The arrangement of the pedal musculature is upon a plan distinct from that already described. Attached by a narrow insertion to the shell dorsal to the anterior end of the anterior adductor lies the protractor pedis muscle (*p.p.*) on either side. It is weakly developed, and its constituent fibres, spreading superficially over the foot, tend to limit themselves to a band which overlies the dorsal visceral part. The anterior retractor pedis muscle (*r.p.a.*) on each side has a double insertion on the shell, the more anterior directly above that of the protractor pedis, the other a

little more posterior, embedded amongst the tubules of the digestive diverticula. From these insertions the muscle passes backwards and downwards into the foot, spreading in a superficial position over the ventral part of the visceral region. The posterior retractor (*r.p.p.*) on each side is inserted on the shell by a small triangular insertion anterior to that of the posterior adductor. The muscle passes forwards into the foot and there occupies the most internal position of any muscle. There are no elevator pedis muscles.

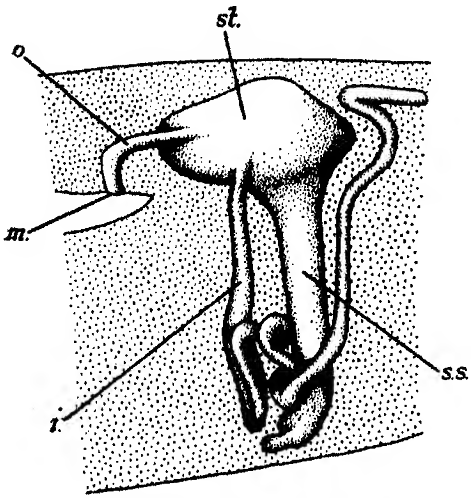

FIG. 11.—*Cultellus pellucidus*. Diagram of the course of the alimentary canal. For lettering, see fig. 2, except that here *s.s.*: style-sac separate from intestine. × 9.

Circular and transverse intrinsic muscles of the foot lie in the visceral part and become of relatively greater significance in the muscular portion.

The gills are long and narrow, the direction of the ctenidial axis being parallel with the edge of the shell. Both demibranchs depend freely into the pallial cavity, stretching from the side of the foot to the inner end of the inhalent siphon. The anterior ends of the gills are slightly deeper than the posterior. The outer demibranch is a little shorter than the inner and leaves the anterior end of the latter exposed. The lamellæ are homorhabdic, and are not folded.

The palps are small, equalling about one-seventh of the total body-length. Each bears about twenty folds.

The mouth leads by a short œsophagus (fig. 11, *o.*), equal to one-twelfth of the animal's length, into the stomach (*st.*), entering on the left side a little behind the anterior end. The stomach is depressed from above downwards. From the mid-ventral surface emerges the style-sac (*s.s.*), a tube of considerable diameter, which passes almost vertically downwards to a point close to the ventral margin of the foot; there it suddenly contracts to a small size and the terminal portion forms an appendix to the rest of the sac. The intestine (*i.*) leaves the stomach from the left side at a point between the entrance of the œsophagus and the origin of the style-sac. It passes ventrally in an almost straight course till it reaches a point near the ventral end of the style-sac—this

stretch is referred to as the ventral or descending limb. At the end of the ventral limb the gut is thrown into a closely packed coil of three or four turns, crosses the left side of the sac and passes, as the dorsal or ascending limb, along its dorsal side, in a relatively straight course, to the posterior end of the stomach, whence it turns sharply back to enter the pericardium.

As in *Gari* and the other types of bivalves described above, the excretory organs of the two sides communicate with each other.

The animals which have been described above under the name *Cultellus pellucidus* were all obtained from Plymouth. According to the recently published faunistic list of the Marine Biological Association (1931) the sole species of this genus which is found there is *Cultellus (Phaxas) pellucidus*, Pennant, also listed by Winckworth (1932) under the same name. In his studies on the soft parts of the Solenidæ Ghosh (1920) separates (p. 61) this particular species of the genus *Cultellus* from the others, and erects for its reception a new genus *Subcultellus*, Ghosh, his reasons being that *C. pellucidus* differs from the other species in several respects, among which are included a fourth aperture, an elongated anterior adductor, a very small posterior adductor, a wedge-shaped foot, a large cæcum (that is, style-sac) with a long course, and in being without a fringe of long tentacles around the distal margin of the siphonal tubes. Amongst other characters of this new genus which the author gives in the diagnosis—drawn from Bloomer's paper (1902*b*)—are the facts that the intestine has two simple limbs and that the "gills" are "similar to those in *Solen*." Reference to his description of the genus *Solen* (p. 52) shows that the gills of that genus are "narrow and elongated . . . plicate and heterorhabdic, the plicæ being free from one another." The last clause of this description I am at a loss to understand, as in no lamellibranch are the plicæ joined to one another save at the base, and in *Solen*, as sections of gills quickly show, the plicæ are firmly fused in that position.

The description of *C. pellucidus* given above differs from this in a few significant points: the intestine has a knot of coils at the junction of the descending and ascending limbs (as Ghosh describes for the other species of the genus), the gills are non-plicate and homorhabdic, and there is a definite collection of long tentacles at the distal ends of the siphons. The inhalent siphon bears two long tentacles in the mid-ventral line, while there are two ventral and two dorsal to the aperture of the exhalent siphon. All are speckled with large numbers of greenish, iridescent points. In addition to these long tentacles there are smaller ones with brown markings forming a fringe round the aperture of the dorsal siphon. I am not certain just what Ghosh intends to convey by the phrase "round

the distal margin of the siphonal tubes." The tentacles which I have just described are situated at the distal end of the siphons, but arise from the external wall, not from the actual margin of the aperture: if Ghosh by the phrase "distal margin" means this latter position, then there is no tentacular fringe in this species.

Whether there are in reality two closely related species of the genus *Cultellus* at Plymouth, or whether there are erroneous observations recorded in the paper by Ghosh, could be decided only by careful examination of large numbers of specimens. It is here desired merely to place the discrepancies on record, as the actual name of the species investigated is quite immaterial to the validity of the argument developed in this essay.

I am greatly indebted to Mr G. A. Steven, of the Plymouth Laboratory, for the opportunity of examining living specimens of this lamellibranch.

Solecurtus scopula.

Such specimens of this species as I have been able to see are about 35×15 millimetres. They are slightly elongated and oval in outline, with the anterior end of the shell a little broader than the posterior, a difference due mainly to the greater angle at which the shell slopes downwards from the hinge on the posterior side. The shell is slightly concave about the middle of each valve, especially close to the ventral margin, but bulges at either end. The hinge is approximately central in position.

The mantle edge bears a broad inner longitudinal fold on each side, and just anterior to the middle of the ventral surface these unite, forming a broad, flat surface through which may be seen the glistening bands of the cruciform muscle. The rest of the mantle edge remains unfused and encloses posteriorly a capacious siphonal space. Anteriorly the two mantle folds are completely separate, from the anterior end of the partition to above the anterior adductor muscle, leaving a broad pedal space. Throughout its whole extent the mantle edge is rather broad, and on its external surface occur a large number of scattered small tentacles.

The siphons are well developed. A large and capacious proximal section, in which the inhalent and exhalent tubes are united, is marked externally only by a few wrinkles without precise arrangement. Distally the two siphons are separate from each other for a short distance equal to about half the length of the fused piece. Here each is marked by annular grooves and the surface is covered with a large number of minute tentacles, arranged without any order. There is no fringe of tentacles around the aperture of either siphon. Within the walls of the siphons the arrangement of the muscle layers is, from outside inwards:

longitudinal, circular, longitudinal, circular, longitudinal, separated by connective tissue from a slender layer underlying the inner lining epithelium; of these the inner longitudinal layers are the best developed and at the bases of the siphons are inserted on the shell, forming the large retractor muscles. In addition to these, strands of transverse muscle pass from the one wall to the other.

In section the shape of the anterior adductor muscle (fig. 12, *a.a.*) is that of an elongate oval, slightly indented on its lower surface for the

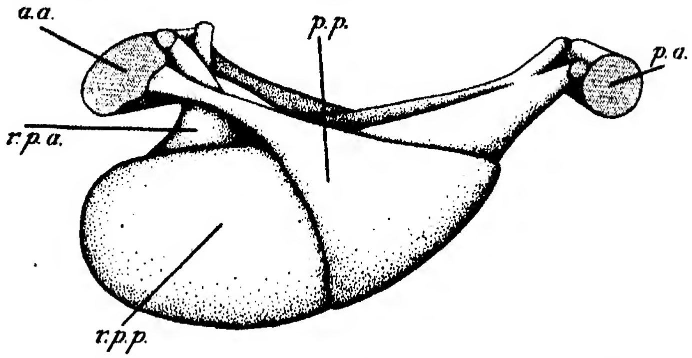

FIG. 12.—*Solecurtus scopula.* Diagram of the arrangement of the muscles. For lettering, see fig. 1. × 3.

attachment of the protractor pedis muscle. The posterior adductor (*p.a.*) is almost circular in section and is not markedly smaller than the other.

The foot is linguiform, without a sole, flattened from side to side and obliquely truncated at its tip. In the mid-ventral line, near the junction of the muscular and visceral portions is the minute aperture of the byssus gland. The protractor pedis muscle (*p.p.*) is developed to a considerable degree on either side and forms a superficial covering to the proximal half of the foot. It is inserted on the lower side of the anterior adductor. The anterior retractor pedis (*r.p.a.*) is attached to each valve by a single small insertion adjacent to the posterior end of that of the anterior adductor. From there the muscle passes ventrally into the foot where it is the most internal of the muscle coats. Between the bundles of the anterior retractor on the inside and those of the protractor pedis on the outside lies the sheet of muscle fibres belonging to the posterior retractor of the foot (*r.p.p.*). These run back to be inserted on the shell by a small circular insertion lying above the anterior portion of the insertion of the posterior adductor.

In addition there is the usual system of circular and oblique intrinsic muscles. There are no elevator pedis muscles.

The gills are long and narrow, but not relatively so narrow as in *Cultellus*. The ctenidial axis runs from a position high on the visceral

mass to the distal end of the common portion of the siphonal tube, ending there on the dorsal side of the inhalent siphon. The outer demibranch has a considerable supra-axial extension, composed of a direct lamella only, and it leaves a large, triangular area of the inner gill exposed. In one rather interesting point this demibranch differs from the usual structure of the lamellibranch gill, in that the longitudinally directed terminal furrow which typically runs along the free edge is absent. Consequently, the length of the filaments is rather variable, so that the demibranch has a wavy edge instead of the normal straight one. The inner gill is typical in this respect. Except for the extreme anterior corner of the inner demibranch — where it lies between the labial palps —the ctenidia are heterorhabdic and plicate: in the excepted position there is neither folding of the lamella nor differentiation of the filaments.

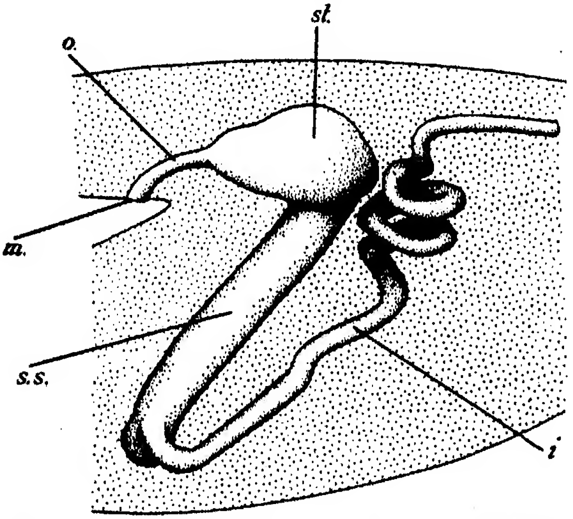

FIG. 13.—*Solecurtus scopula.* Diagram of the course of the alimentary canal. For lettering, see fig. 2. × 3.

The two palps on either side are, in length, equal to about one-sixth of the total length of the animal, each with about twenty folds.

The mouth (fig. 13, *m.*) leads through the short œsophagus (*o.*) to the stomach (*st.*) which is somewhat pear-shaped with the bulge of the pear forming the posterior half. On the ventral side this is continued into the broad tube which forms the united style-sac and intestine (*s.s.*), passing ventrally into the foot and curving slightly in an anterior direction as it does so. At the ventral end of this common portion the intestine (*i.*) leaves the style-sac and passes dorsally, almost parallel to the previous portion, to the posterior end of the stomach, coiling into two circles on the way, and thence running back through the pericardium.

Solecurtus chamasolen.

This species differs from the preceding one in points of relatively minor importance which can in no way affect the results of a comparison with the other bivalves dealt with here.

The proximal fused portion of the siphons is much abbreviated and the separate distal parts correspondingly lengthened. The ventral siphon is about half as long again as the dorsal. Both tubes are smooth over the surface of their common section, but the distal free parts are marked by annular grooves and bear an exceedingly large number of fine tentacles, some apparently scattered at random over the general surface, but many arranged in definite longitudinal rows, overlying the course of the nerves within.

Discussion.

Of the series of anatomical descriptions which have just been given, the first five are representative of members of the Tellinacea, whereas the sixth, that of *Cultellus pellucidus*, may be taken as typical of the Solenidæ. The two last refer to members of the Solecurtidæ, and a decision must now be reached as to which of the two groups of bivalves they most closely resemble.

Through the members of the Tellinacea, it will be realised, runs a strong thread of similarity, and it would be no difficult task to create from their descriptions an ideal Tellinacean possessing all the fundamental features of the group. Such a lamellibranch would be oval in shape, without any extensive mantle fusions, possessing a cruciform muscle; the foot linguiform and byssiferous, the siphons long, separate, and capable of retraction within a siphonal space; the posterior adductor muscle approximately equal in size to the anterior, which is oval in shape; the anterior retractor pedis muscle with a single insertion on each valve, and lying, in the foot, *internal* to the posterior retractor; the protractor pedis muscles well developed, the outer demibranch with a supra-axial extension and leaving a large part of the inner exposed; the palps large, the œsophagus long, and the style-sac and intestine fused for the first part of their course.

On this theme each of the types described is a variation.

In contrast with this set of animals have now to be set the characters of *Cultellus pellucidus*, which, reference to the many papers of Bloomer will show, is not unfairly taken as representative of that characteristic group of bivalves popularly known as the razor fishes, and of which, no less than of the Tellinacea, an ideal member may be pictured. In this case the shape is markedly elongated, the length being three, four, or even more times the breadth. Extensive mantle fusions occur, altering the dispositions of the fibres of the orbicular muscle and usually leading to the persistence of a fourth aperture towards the anterior end of the expanse of fused ventral surface. There is never a cruciform muscle.

The foot is more or less cylindrical and frequently has a flattened, terminal sole; the byssus gland is usually lost. The siphons are short and there is no siphonal space into which they may be withdrawn; their internal musculature is reduced. The posterior adductor is much smaller than the anterior, which is always narrow and elongated. The anterior retractor muscle of the foot has two insertions on each valve, and, in the foot, lies *external* to the posterior retractor. The protractor pedis muscle is either reduced and poorly developed, or is absent altogether. The gills are long and narrow and the two demibranchs are almost equal in size, the outer without a supra-axial extension. The labial palps are relatively small. The œsophagus is short, and the style-sac and intestine are separate throughout.

If a careful comparison be now made between the description of the two species of *Solecurtus* given above, and the two abstract types which have just been built up, it will be seen that with regard to such features as shape, presence of a cruciform muscle and the structure of the foot, siphons, adductor and pedal muscles, supra-axial extension of the outer demibranch, palps, and style-sac and intestine, *Solecurtus* falls decidedly alongside the Tellinacean type.

From that ideal it differs in respect of the degree of fusion of the mantle folds, in the basal union of the siphons, the elongated gills, the reduction in the size of the protractor pedis. These are, however, when contrasted with the points in which *Solecurtus* agrees with the Tellinacea, points of relatively lesser importance, and cannot substantially influence the results of the comparison. They are entirely outweighed by factors like the similarity of structure in the pedal musculature and the course of the alimentary canal.

The Solecurtidæ may, then, be most logically placed with the Tellinacea, although there appears to be in their organisation a number of points characteristic of the Solenidæ, and suggestive of a close relationship with that family. This probably indicates a real genetic affinity, meriting the inclusion of both Tellinacea and Solenacea in a common group. Some, at least, of these points of resemblance may be due to convergence consequent upon both families having adopted similar habitats and modes of life. The Solecurtidæ are to be regarded as a group of lamellibranchs linking the Tellinacea with the Solenacea, but themselves retaining many more primitive features than do the Solenacea, and therefore falling themselves in the former group.

It is difficult to conceive why the cruciform muscle should have disappeared from the Solenidæ without leaving any trace of its existence, and, on this basis, it must be assumed that that family separated from the

ancestral forms of the Solecurtidæ and the other Tellinacea before the evolution of that organ had taken place, and probably, too, before the acquisition of a supra-axial extension by the outer demibranch, a feature which has persisted throughout the Tellinacea and has been exaggerated by its higher members. Since their separation from the ancestral stock the Solenidæ have evolved along a well-defined line of their own, acquiring those features which are their characteristic property.

Of the Tellinacea, apart from the Solecurtidæ, *Gari* may be looked upon as one of the more primitive forms. *Tellina*, while resembling it in general features, is probably less so, as the supra-axial extension of the outer demibranch has now become so large as to involve the complete gill, with the result that it is reduced to a direct lamella only throughout the greater part of its length. This genus appears to be the base of a small group leading through *Macoma* to *Scrobicularia*. In all, the gill structure is similar, apart from variations in the degree of plication, but this has been shown by Ridewood (1903) to be without any great phylogenetic significance. The seriation of these three genera is well brought out by comparison of the structure of the cruciform muscle (Graham, 1934) and of the course of the alimentary canal (see figs. 5, 6, 7). In *Tellina crassa* the intestine, after becoming free from the style-sac, passes dorsally out of the foot by a rather irregularly coiled course. In *Macoma balthica* the length of this portion of the alimentary canal has been greatly increased, due to the fact that the intestine has two short spiral coils. In *Scrobicularia plana* the coiling of the gut has become even more complex: the intestine has a short free course on leaving the style-sac and passes almost at once into a series of coils built upon an exactly similar plan to those of *Macoma* with the convolutions exaggerated. The style-sac now points in a posterior direction, almost as if it had been pulled back out of its normal vertical, or even slightly anteriorly directed position, because of the greater and greater portion of the ascending limb of the intestine which has become involved in the spiral coiling. It is difficult to see any connection between this increased length in the intestine and the estuarine habitat of these two genera.

All these members of the Tellinacea are obviously closely related. One genus, however, stands apart from the others, *Donax*, separated by several distinct differences, amongst which may be mentioned the retention of the elevator pedis muscles, the separation of the style-sac from the intestine, the coiled descending limb of the latter and simple ascending one, and the closed condition of the sense organ associated with the cruciform muscle (Graham, 1934). The persistence of the elevator muscles of the foot leads to the conclusion that *Donax* must have been separated at a very early

stage from the ancestral Hemidapedont stock as these are not separately represented in any other member of the Tellinacea or of the Solenacea that I have examined (but see p. 164). During the long course of time since it has been isolated as a distinct type of lamellibranch the other peculiar feature of this genus have been elaborated. The loss of the byssus gland and the separation of the style-sac from the intestine must have been accomplished as distinct achievements in this genus independently of the same changes occurring in the Solenidæ.

Summary.

1. A comparative description of the anatomy of the five following bivalves belonging to the Tellinacea is given: *Gari tellinella*, *Tellina crassa*, *Macoma balthica*, *Scrobicularia plana*, and *Donax vittatus*.

2. A description of one member of the Solenidæ, *Cultellus pellucidus*, is given.

3. The anatomy of two members of the Solecurtidæ, *Solecurtus scopula* and *S. chamasolen*, is described.

4. On the basis of these descriptions the family Solecurtidæ is shown to be more properly classified with the tribe Tellinacea than with the Solenidæ.

5. The relationships of the above lamellibranchs are discussed.

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(*Issued separately August* 20, 1934.)

XVI.—On a New Species of *Psygmophyllum* from the Upper Carboniferous of Scotland. By Jessie A. R. Wilson, B.Sc., Ph.D., University of Glasgow. *Communicated by* Professor J. Walton, D.Sc. (With Plate.)

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THE material which forms the subject of this present paper was found in Coal Measure Shales exposed in the bank of the River Nethan, near Crossford, Lanarkshire, Scotland. The geological age of these beds is the Productive Coal Measures, Upper Carboniferous. The outcrop is near the position of the Kiltongue Musselband, about 8 fathoms above the Kiltongue Coal.

The specimens occur on two slabs of shale, one with a single isolated impression and the other, found by Miss Edith A. L. Mackay, B.Sc., showing three impressions of *Psygmophyllum* leaves in association with *Annularia* sp., *Urnatopteris tenella* Bgt., and *Sphenopteris* sp. All four leaves are detached and appear to be incomplete, judging from the ragged edge of the base and apex.

The block on which the single specimen occurs is a very soft, grey, micaceous shale; the impression itself showing a brownish hue (fig. 6). Transfers were made from portions of this impression and subsequently macerated. Small pieces of thin cuticle were obtained, but no cell outlines could be detected on them. This leaf measures 4½ cm. in length, but the complete leaf was longer, as the true apex and base are missing in this specimen. The lamina is divided medianly into two segments, of 5 mm. and 7 mm. in breadth. The veins which are fairly distinct are fine, parallel, and dichotomise frequently (fig. 7). The number of veins in the upper part of the lamina is four per millimetre of breadth; anastomoses have not been observed in this specimen.

The other specimens occur on a somewhat firmer shale, the leaf-impressions being of black carbonaceous material, which is incomplete in parts. The best preserved and most complete of the three leaves is shown in figs. 1 and 2. The leaf is narrow in form, contracting gradually towards the base. It is impossible to say whether the actual base of the leaf is preserved or not, but judging from the small number of veins in the lower part of the lamina it would suggest that this leaf had broken off near its point of attachment. It is also difficult to determine if the true

apex is present, but the two segments of this leaf appear to narrow and terminate in an obtuse point (fig. 1). The leaf would thus appear to be almost complete, measuring 5 cm. in length. The lamina at the base is 2 mm. in breadth; after the bifurcation 4–5 mm. The venation is coarser than in the other specimen previously described. Four veins enter at the base of the leaf, each of which dichotomises about the same level; the resulting veins each divide again before the bifurcation of the lamina, and in the upper segments the veins are three per millimetre of breadth and show frequent dichotomies. Anastomosing of the veins is found, but is of rare occurrence; the only two cross veins which have been observed on these leaves can be seen in fig. 5.

Each of the four leaves shows bifurcation of the lamina. Segmentation of the lamina in *Psygmophyllum* leaves is of frequent occurrence, but is often due merely to tearing; but in the specimens described in this paper the division of the leaves appears to be an original feature of the living leaf and not due to any imperfection of the leaf before preservation. Figs. 4 and 5 show one of the three leaves present on the larger slab of shale. There is no evidence of ragged or torn edges of the leaf-margin in the angle between the two segments (fig. 5), which suggests that the forking of these leaves is an original feature.

Diagnosis.

Psygmophyllum scoticum sp. nov.

Leaves small, about 5 cm. in length, narrow, tapering gradually towards the base. Lamina divided medianly into two segments. Veins few in number, 3–4 per millimetre of breadth in upper part, radiating throughout with frequent dichotomies.

Upper Carboniferous (Productive Coal Measures, near the position of the Kiltongue Musselband, about 8 fathoms above the Kiltongue Coal). Left bank of River Nethan, about 140 yards east of the bridge across the River Nethan, between Corramill and Holmhead, near Crossford, Lanarkshire, Scotland.

This new species of *Psygmophyllum* has been named *Psygmophyllum scoticum*.

Discussion.

The genus *Psygmophyllum* as defined by Schimper (1870, p. 192) included both entire and divided leaves, but Arber (1912, p. 397) prefers to restrict this generic name to leaves which are entire or slightly divided into broad, palmate lobes, and to exclude from this genus, for the

present, those leaves which are deeply divided, such as *Psygmophyllum Grasseti*. This species he refers to the genus *Ginkophyllum* (Arber, 1912, p. 402).

The specimens from the River Nethan do not possess the broad, flabellate form of the type species, *Psygmophyllum flabellatum*, L. and H., but can be referred to the genus *Psygmophyllum* if the wider definition by Schimper is accepted. This new species is small in dimensions compared with those already recorded. In form it resembles *Psygmophyllum Kidstoni* (Seward, 1903, p. 93, pl. 12, fig. 1), but this South African species is much larger, being 13 cm. in length. The forking nature of the leaves recalls the divided lamina of *Psygmophyllum Grasseti* (Saporta, 1879, p. 186, fig. 15 (5)) and *Psygmophyllum cuneifolium* (Kutorga, 1838, p. 32, pl. 7, fig. 3; Zalessky, 1918, pl. 7, fig. 3), and compares favourably in size with some of the ultimate forks of these leaves, but, as previously remarked, the River Nethan specimens most probably represent complete leaves. This new species apparently differs quite considerably from any of those previously described, particularly in size.

The genus *Psygmophyllum* is probably an artificial one. Up to the present only leaf-impressions have been discovered, nothing being known of anatomical structure or of fructifications. The majority of the species occur as detached leaves, but in some instances the leaves are found attached to an axis. It comprises more than a dozen species, varying widely in locality and horizon. A résumé of the genus, with descriptions of the main species, has been given by Arber (1912, p. 397) and Seward (1919, p. 79), but several new species have since been described, viz.:

Psygmophyllum Potanini (Schmalhausen) Zalessky, from the Permian of Mongolia (Zalessky, 1918, pls. 1, 2, 3, 4, 7).

Psygmophyllum Purkyněi Šusta, from the Upper Carboniferous of Silesia (Nemejc, 1927).

Psygmophyllum (?) *pusillum* Nathorst, from the Devonian of Spitzbergen (Nathorst, 1920, p. 5, fig. 1).

Psygmophyllum multipartitum Halle (placed provisionally in the genus *Psygmophyllum*), from the Permian of China (Halle, 1927, p. 215, pls. 57, 58).

Psygmophyllum Gilkineti Leclerq, from the Middle Devonian of Belgium (Leclerq, 1928).

Psygmophyllum has a wide geographical distribution and extends from Middle Devonian to Permian periods. There were before the discovery of these Scottish specimens only two authentic records of

Psygmophyllum from Britain, occurring in the Upper Carboniferous Coal Measures.

1. *Psygmophyllum flabellatum*, from the Newcastle Coalfield (Seward, 1919, p. 81, fig. 665).
2. *Psygmophyllum* sp., from Derbyshire.*

A leaf attributed to the genus *Psygmophyllum* has been found in the Middle Devonian of Caithness (Seward, 1931, p. 139).

It is of interest that *Psygmophyllum scoticum* sp. nov. is the first record of the genus from Carboniferous Rocks of Scotland.

In conclusion, I desire to express my thanks to Professor J. Walton for his continued interest and helpful criticism during the preparation of this paper.

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* Dr Crookall, in a letter to Professor Walton, makes reference to this species which is of the Cyclopteroid type. The specimen is included in the Kidston Collection (No. 5436) and was collected by Moysey from just below the Top Hard Coal (Yorkian) at Shipley Claypit, Ilkeston, Derbyshire.

DESCRIPTION OF PLATE.

Psygmophyllum scoticum sp. nov.

Fig. 1.—An almost complete leaf. (Nat. size.) (From collection in Botanical Dept., Glasgow.)

Fig. 2.—Leaf of fig. 1 enlarged, showing the dichotomy of the veins. (× 2½.)

Fig. 3.—Drawing of portion of the leaf, illustrated in figs. 1, 2, to show the venation. (× 3.)

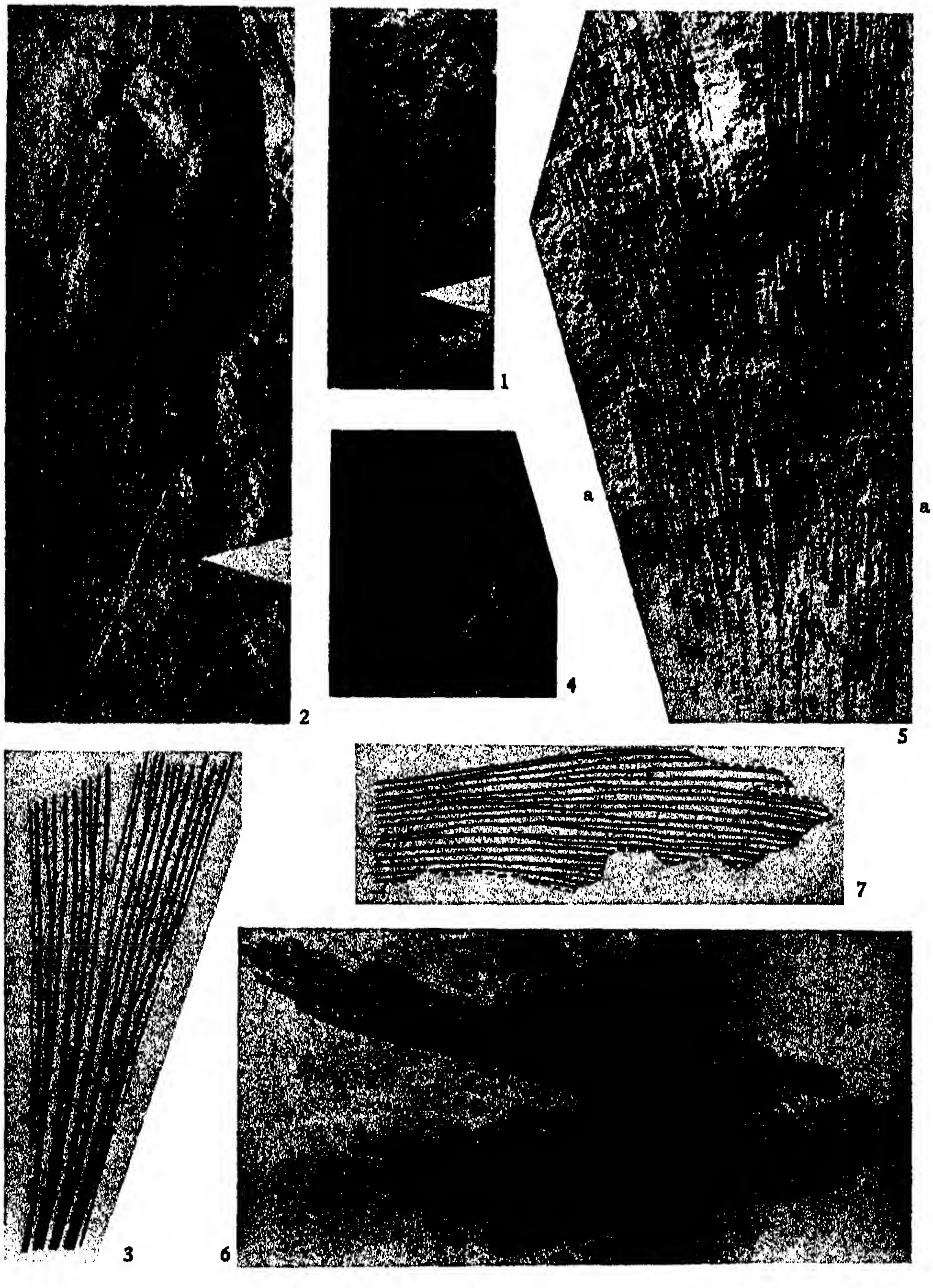
Fig. 4.—Single leaf from the larger block of shale. (Nat. size.)

Fig. 5.—Portion of the leaf illustrated in fig. 4, showing clearly the angle between the forking segments of the lamina. (× 5.) *a* = anastomosis of veins.

Fig. 6.—An incomplete leaf from the softer, micaceous shale. (× 2 approx.)

Fig. 7.—Drawing of portion of the leaf, illustrated in fig. 6, to show the venation. (× 4.)

(*Issued separately September* 1934.)



J. A. R. W., photo. Zinco-Collotype Co., Edinburgh.

Psygmophyllum scoticum, sp. nov.

OBITUARY NOTICES

Arthur Henry Hallam Anglin, M.A., LL.D., M.R.I.A.

PROFESSOR ANGLIN was born at Cork in 1850, and educated at Queen's College, Cork (graduating in the Queen's University of Ireland with First Class Honours and a Gold Medal in 1868), and Peterhouse, Cambridge, graduating in the Mathematical Tripos of 1874. From 1874 to 1887 he held scholastic appointments, but in 1887 he was elected Professor of Mathematics in University College, Cork, a post which he occupied until his retirement in 1913.

He was elected a Fellow of the Society in 1881, being thus one of the oldest Fellows at the time of his death, which took place on January 25, 1934. By his marriage to Miss Gertrude M. Alexander, of Dublin, he left one son.

Anglin's scientific work was in the fields of algebra, geometry, and trigonometry, and was published in the *Proc. R.S.E.*, *Proc. R. Irish Acad.*, *Proc. Edin. Math. Soc.*, *Messeng. Math. Quart. Journ. Maths.*, *Arch. Math. Phys. Lpz.*, *Journ. reine angew. Math.*, *Journ. de Math.*, and *Bull. Soc. math. Fr.*, from 1883 to 1903.

E. T. W.

Henry Moubray Cadell, LL.D., F.S.A.Scot., M.Inst.M.E.

THE sudden death of Dr H. M. Cadell on April 10, 1934, removed an outstanding figure in the scientific life of Scotland. Born in 1860, he came of a family which had long and close associations with West Lothian. His great-grandfather William Cadell (1737–1819) was one of the founders of the Carron Co. in 1759 and a pioneer in the industrial development of the Bo'ness district. From his father Henry Cadell he inherited a bent for geology and mining, subjects to which he was to devote the greater part of his long life. After graduating in science at the University of Edinburgh in 1882 he proceeded to Germany to continue his studies at the Clausthal Royal Mining Academy. In 1883 he joined the staff of the Geological Survey, taking part in the survey of the North-West Highlands and carrying out between 1884 and 1887 the first detailed examination of the oil-shale fields of the Lothians. On the death of his father in 1888 he was called to the management of the family estates, and from this time onwards was prominently identified with administrative and public work of all kinds in his native county. Among the many posts which he held were those of Deputy Lieutenant, Justice of the Peace, and County Councillor.

His activities as land-owner and colliery proprietor and the manifold public duties which he undertook did not prevent him from pursuing his geological researches with characteristic energy. A vigorous and vivid writer and an expert draughtsman, he was the author of a large number of important publications dealing with many different aspects of Scottish geology. His earliest paper, "Notes on the Volcanic Rocks of the Borrowstounness Coalfield," appeared in the *Transactions of the Edinburgh Geological Society* (vol. iii, part iii, pp. 304–325) as long ago as 1880, and the long series of papers which followed testify to the wide range of his interests. Among these may be noted the valuable and suggestive paper on "The Dumbartonshire Highlands," in the *Scottish Geographical Magazine* for 1886, where he advanced the view that certain of the through-valleys of the Western Highlands are relics of a very early and now disrupted drainage-system, and the classic paper on "Experimental Researches in Mountain Building," presented to this Society in 1888 (*Transactions*, vol. xxxv, part i, 1889, pp. 337–357), in which he showed that it was possible to reproduce experimentally many of the structural phenomena associated with the post-Cambrian thrust-

movements in the North-West Highlands. In 1886 appeared his "Geology of Sutherland" (*Sutherland Association Papers*), an enlarged and revised edition of which was published in 1896 under the title of *Geology and Scenery of Sutherland*. He contributed in 1901 an important paper on the oil-shale fields of the Lothians to the *Transactions of the Edinburgh Geological Society* (vol. viii, part i, pp. 134–163) and collaborated with the late J. S. Grant Wilson in preparing the first edition of the *Geological Survey Memoir* on the "Oil-Shales of the Lothians," which appeared in 1906. In *The Story of the Forth* (1913) and in *The Rocks of West Lothian* (1925) he gathered together the results of his long study of West Lothian geology, and these two volumes, dealing with subjects of which he had an unrivalled knowledge, must for long remain storehouses of information on the geological history and industrial development of this part of Scotland. He pursued many lines of research, but his main bent lay towards the study of physiographic and glacial problems, and his contributions to our knowledge of the development of the river-systems of the Midland Valley of Scotland are perhaps his most outstanding scientific achievement.

Dr Cadell was keenly interested in land-reclamation questions. As long ago as 1889 he began experiments with a view to reclaiming part of the foreshore to the east of Bridgeness, and was successful in converting a considerable area into a site for industrial works. As a member of the Forth Conservancy Board (instituted in 1921) he also took a prominent share in the scheme for reclaiming portions of the foreshore to the west of Bo'ness. A full account of these operations is given in his papers on "Land Reclamation in the Forth Valley," contributed to the *Scottish Geographical Magazine* in 1929 (vol. xlv, pp. 7–22, and 81–100).

Dr Cadell was an original member of the Royal Scottish Geographical Society and served at different times as Member of Council, as Chairman of Council, and as Vice-President. He was elected a Fellow of the Edinburgh Geological Society in 1880 and of the Royal Society of Edinburgh in 1887, serving on its Council from 1919 to 1922. For the former society he acted as Secretary from 1888 to 1897, and twice occupied the Presidential chair (1898–99 and 1927–28). In 1932 his old university conferred on him the honorary degree of LL.D.

It would be impossible to conclude this brief account of his career without paying tribute to his striking personal qualities, his high sense of duty, and his humane outlook. A man of broad culture, sincere and thorough in all he undertook, sympathetic and generous in his dealings with others, he will be long remembered by a wide circle of friends.

M. M.

Santiago Ramón y Cajal.

SANTIAGO RAMÓN Y CAJAL was easily the greatest scientific man that Spain has produced in modern days. Before he began his histological work our knowledge of the minute structure of the nervous system and the relations of its parts was fragmentary and inexact. It was largely based on conjecture, and the views which were held by physiologists regarding the relation of its parts to one another had no well-grounded basis of anatomical fact. Such a basis was supplied by Cajal, and led to a complete clearing up of our conceptions regarding its mode of operation.

This depends on the fundamental fact that the elements of the nervous system, both those which serve actively to carry nerve-impulses and those which play a more passive part, are morphologically disunited. Before Cajal the opposite view was universally held. The central nervous system was conceived as an intricate network of intercommunicating fibres which were not positively known to have any anatomical connection with nerve-cells. It is true that Waller had shown that certain nerve-fibres when cut off from the groups of cells from which they emanate undergo degeneration and death; but the relationship between cells and fibres was not understood, and nerve-cells were conceived and spoken of as distinct from nerve-fibres. Even to-day neurologists speak of the nerve-cells as distinct structures, although they are well aware that a nerve-fibre is always part of a nerve-cell, however far it may have extended away from the nucleated body whence it originated! It is Cajal's merit to have shown this relationship to be beyond question, that every nerve-fibre is part of a nerve-cell, and that to designate a nerve-cell by a special name (neurone) is unnecessary and misleading. Yet so universally has the term been adopted that he himself is constrained to employ it, much against his better judgment!

Cajal was fortunate that when his investigations on the nervous system were beginning a new method for showing the elements of that system in a manner in which they had never before been so clearly displayed was being evolved under the auspices of Camillo Golgi. By this (the silver chromate method) it is possible in any portion of the nervous system to select out of an intricate mass containing hundreds of nerve-cells a few—it may be only one or two—which are stained intensely black. These few are stained in every part, not only the main part or cell-body,

but all the processes, no matter how numerous nor how far they may extend from the cell-body; the rest of the cells remain wholly unstained. Taking advantage of this selective staining—which has never been properly accounted for—Golgi found that it is possible to trace nerve-fibres for long distances from their origin in one nerve-cell to their, generally arborised, termination in another part of the grey matter. Cajal adopted this method, modified it, and applied it successfully to all parts of the central nervous system, utilising especially young or fœtal animals, for the greater ease of following the course of the nerve-tracts and fibres under investigation. Proceeding in this way he was able gradually to build up not only a clear idea of the relations with one another of the cells constituting the main nervous system, but also of the structure of outlying portions, such as the retina, and the relationship of its various layers to one another and to the main central nervous system itself. So extensive has been the range of his investigations that Cajal may be said to have left no part of the nervous system unexamined. In every case the same principle obtains, viz., that the nervous system is composed of anatomically disunited elements. When, in 1894, he began his investigations, the subject was chaotic; he has left it ordered and comprehensible. He has lived to see his life's work largely accomplished and his conclusions almost universally accepted. What the anatomist, the physiologist, the pathologist, and the clinician owe to that work cannot easily be overstated! No better illustration of the principle that for the investigation of function an adequate knowledge of structure and especially of minute structure must first be acquired can be adduced. Without the illumination which Cajal's work has thrown upon the structure of the nervous system, we should still be groping in the dark, still theorising about the manner in which its most fundamental functions are carried on!

Born in 1852, Ramón y Cajal was the son of a Professor of Anatomy; but so far as microscopic anatomy is concerned he appears to have been self-taught. In 1884 he was himself appointed to the Chair of Anatomy at Valencia, and it was here that he began the systematic study of the nervous system, which was to constitute his life's work and bring him fame. From Valencia he transferred to Barcelona and eventually to Madrid. Here he founded a school of histology which has become world-famous. Honoured all the world over, he was also appreciated by his own countrymen, who are justly proud of him. His name is perpetuated in Madrid by the magnificent "Instituto Cajal," where, after his retirement from active teaching, he continued his histological investigations, which later embraced many more subjects than the nervous system, and were conducted largely in association with his assistants and pupils.

He visited London in 1894 to give the Croonian Lecture before the Royal Society. The Physiological Society entertained him at an informal banquet—and many of us older physiologists had the opportunity of then making his acquaintance, which in some cases developed into an enduring friendship. It was only a few months ago that the writer received from him (with a charming personal message) a copy of his latest work, *Neuronismo o Reticularismo*, a short but very able recapitulation of the arguments and evidences which had led him to the conclusions regarding the structure of the nervous system upon which his fame will always be based. He died at the age of eighty-three on October 17, 1934, in full possession of his faculties and working until the last.

Ramón y Cajal's scientific communications were mostly published in Spanish, but some of the most important have been translated into French and English: amongst the latter may be mentioned an early work, *New Ideas on the Structure of the Nervous System*, the *Textura del Sistema Nervioso*, and the more recent *Degeneration and Regeneration of the Nervous System*. He edited for many years an important histological journal, which is largely constituted of articles by himself and his fellow-workers. Begun in 1896 as *Revista Trimestral Micrográfica*, and continued as *Trabajos del Laboratorio de Investigaciones Biológicas*, it has appeared also under the French title *Travaux du Laboratoire de Recherches Biologiques*, and is characterised by the excellent manner in which it is printed and illustrated as well as by the important nature of its articles, which furnish abundant evidence that the influence of Ramón y Cajal will long continue to assert itself in the sphere he had made peculiarly his own.

He was elected a Foreign Member of the Royal Society of London in 1909, and an Honorary Fellow of this Society in 1913.

E. S-S.

George Coull, D.Sc. (Edin.)

George Coull was born in Edinburgh in 1862. He was educated in Daniel Stewart's College, where he obtained many prizes. On leaving school he was apprenticed to a pharmaceutical chemist, and soon showed evidence of his ability by securing the various prizes open to young pharmacists. After attending classes at Surgeon's Hall and Heriot-Watt College, he passed the qualifying examinations of the Pharmaceutical Society. Entering Edinburgh University, Coull was Senior Medallist of his year in chemistry. He graduated B.Sc. in 1889 and D.Sc. in 1899, his thesis discussing the preparation of phenyl betaine. After graduating, Dr Coull was appointed chemist and laboratory manager to Messrs Raimes, Clark & Co., Leith. When the British Pharmaceutical Conference visited Edinburgh in 1892 he read three papers, one of them proving that there were two phosphates of quinine on the market, varying in chemical composition, and therefore giving a different dose of alkaloid for the same weight. In due time he became Managing Director of his firm. For several years Dr Coull was a member of the Board of Examiners for Scotland of the Pharmaceutical Society, and, for a longer period, of the North British Executive of the same society. In 1913 he was elected to the Town Council of Leith, and before long became a Bailie of that Burgh. As a member of the Gas Commission, and other municipal boards, his scientific knowledge was of real service.

George Coull was a man of a genial disposition, with a strong sense of humour which endeared him to a large circle of friends. He died on January 10, 1934, and is survived by a widow and two sons and by two daughters.

He was elected a Fellow of the Society in 1929.

D. B. D.

James Cossar Ewart, M.D., LL.D., F.R.S.

JAMES COSSAR EWART was the younger son of John Ewart of Penicuik, Midlothian, where he was born in November 1851. He spent his boyhood at Penicuik, and was educated there until he entered the University of Edinburgh as a medical student in 1871, graduating as a Bachelor of Medicine and Master of Surgery in 1874. He then became Demonstrator of Anatomy under William Turner, but he relinquished this post in less than a year on being appointed Curator of the Zoological Museum at University College, London. Here he made a number of skilful preparations of various animals, besides assisting Ray Lankester in organising his new class in practical zoology and in taking charge of the class in Lankester's absence. While he was in London he published several original papers dealing with the structure of the retina and lens, the sexual organs of the lamprey, the vascular peribranchial spaces and the valves in the umbilical arteries of the lamprey, and the placentation of the Shanghai River deer. He also contributed to the study of various bacterial organisms, being awarded a gold medal for a research on *Bacillus anthracis*, which he presented as a thesis for the degree of Doctor of Medicine at Edinburgh. In 1878 he returned to Edinburgh to become Lecturer in Anatomy in the Extra-mural School, but he held this position only two months, for at the end of the year he was appointed to the Chair of Natural History in the University of Aberdeen.

It was at Aberdeen that Ewart first became interested in marine biological investigation, and to further his researches he established an experimental station on the adjacent coast. Here he worked in his spare time for three years on fishery problems as well as on the locomotor system of echinoderms in conjunction with George John Romanes, with whom he gave jointly the Croonian Lecture to the Royal Society in 1881. The following year Ewart became Regius Professor of Natural History in his old University, and he held this position for forty-five years, retiring in 1927. Shortly after his appointment he reorganised the courses of instruction in zoology and established new practical classes, and at later stages he was the means of instituting new lectureships in embryology (held first by George Brook and afterwards by Dr John Beard), in invertebrate zoology (to which Dr J. H. Ashworth, now Professor of Natural History, was appointed), and in genetics (the occupant of which was the late A. D. Darbishire, who did valuable pioneer work on heredity).

Ewart joined the Fishery Board of Scotland as scientific adviser in 1882, and afterwards published a number of papers on the fertilisation of herring ova and the natural history of the herring, cod, and other

fish. These were followed by memoirs on the electric organ in the skate (three papers in the *Phil. Trans.*) and on the lateral sense organs of Elasmobranchs (two papers in the *Trans. Roy. Soc. Edin.*, one of which was published jointly with J. C. Mitchell). The work on the electric organ of the skate in particular attracted much attention, for Ewart showed that it was a rudimentary or developing organ and not a degenerate one, and he succeeded in tracing its evolution through such a species as *Raia radiata*, where the muscular tissue from which the structure is derived is only slightly modified, to *R. batis*, where the modification into electric tissue has much advanced, and so to other species in which the electric organ is functionally fully developed. The Duke of Argyll was not slow to point out that the existence of these transitional structures lent no support to the Darwinian theory of natural selection, since in their rudimentary condition they could be of no possible use to the possessors, and Romanes, in commenting on this criticism was forced to admit its validity, but at the same time remarked on the unique character of the organ in the skate.

Ewart next turned his attention to the development of the horse, and more particularly the bones of the limbs, in which he showed that at a certain stage of fœtal development the vestiges of the phalangeal bones of the second and fourth digits were present, and that these subsequently became ossified, fusing with the metacarpals or metatarsals. This discovery was of great interest in the light of the theory of evolution, supplying a striking confirmation of the palæontological evidence relating to the reduction of the digits in the progressive history of the Equidæ as found fossil in successive strata.

It was about 1894 that Ewart started that long series of investigations in experimental breeding, which are probably the most widely known of all his work. In such researches he was to a large extent a pioneer, for since the work of Darwin there was no one, at any rate in Britain, who devoted himself to this kind of investigation. Much of his work was done before the rediscovery of Mendel's laws of heredity, but by adopting such methods as were known to him he carried out important researches on cross-breeding, inbreeding, reversion, etc., among various breeds of horses and other domestic animals. His most famous experiments were probably those on telegony, or the theory that a previous sire may so "infect" the dam served by him as to leave his mark on her subsequent offspring by other sires. The belief was widely entertained by practical breeders and has not yet been wholly discarded, but Ewart's carefully constructed and controlled experiments on various animals (horses, dogs, fowls, etc.) produced uniformly negative results. The classical case of supposed telegony and one in which Darwin himself

believed was that of Lord Morton's Arab mare which, after being mated with a quagga and producing a striped hybrid foal, was afterwards served by an Arab stallion by which she had a foal with certain striped markings that were believed to have resulted from the previous mating with the quagga. Ewart repeated the experiment, using a Burchell's zebra stallion which served a number of mares. These produced hybrid foals, and afterwards pure bred foals by stallions of their own breeds, but the pure bred foals never showed any evidence of having in any way been derived from the previous zebra sire. The results of these experiments, together with other investigations on animal breeding, were published in a volume entitled *The Penycuik Experiments* (1899). These studies led Ewart to investigate the ancestry and evolution of horses and ponies by adopting the methods of experimental cross-breeding, and he showed that the striping which often occurs on the shoulder and legs of the Norwegian pony, the Arab, and other breeds was of the nature of a reversion to a striped ancestor. As a further result of his experiments he arrived at interesting conclusions of far-reaching importance as to the multiple origin of modern horses, pointing out that the "Celtic pony" (still found pure or almost pure in the Hebrides, Iceland, etc.), which had no hind chestnuts or hock callosities, was almost certainly a different species from the primitive "forest type," represented by the heavy horses of the present day such as the Shire, Percheron, and Gudbrandsdal of Norway, which have large hock callosities. Ewart's views with their various implications are admirably summarised by him in an appendix, on *The Making of the Shetland Pony*, to Dr and Mrs Charles Douglas's book on that breed (1913).

Ewart's theories regarding equine ancestry received some support from the discovery of horses' skulls in the Roman Camp at Newstead where he found the "Celtic" or "plateau" type represented, and he contributed a paper on this subject to the *Trans. Roy. Soc. Edin.* (1907). He also found five fairly distinct types of oxen in the same camp and others that he supposed to have been probably cross-bred, and in the light of these discoveries, together with other facts, he wrote upon the origin of domestic cattle without, however, coming to any very definite conclusions (1911). Ewart next turned his attention to the study of sheep and their wild ancestors (1914–15), and expressed the view that not only the mouflon and the urial, but also the Argali or Ammon sheep had a share in forming certain modern breeds (*e.g.* the Scottish Blackface and the Merino). His conclusions were based on the examination of remains from Pleistocene deposits, on a comparison between the skeletons of wild species and primitive and modern breeds, and on cross-breeding experiments.

The work on horses and other animals referred to above was carried out at a private experimental station instituted by Ewart, and conducted very largely at his private expense at Penicuik, to which he returned after living a few years in Edinburgh. In 1913, however, the University of Edinburgh rented a farm at Fairslacks, where Ewart carried out investigations for the improvement of the sheep's fleece, and this work brought him into contact with the woollen industries of Great Britain, and he became an active member of the Council of the Woollen and Worsted Research Association at Leeds. In 1923, at the invitation of the New South Wales Government, he went to Australia, where he visited many important and some very remote sheep stations, and later he proceeded to New Zealand to conduct similar inquiries there. His work was recognised by the Worshipful Company of Woolmen of London, who in 1924 struck a gold medal which they presented to him at a dinner in the City.

It was chiefly as a result of Ewart's knowledge and experience that in 1913 the Board of Agriculture for Scotland formed a special committee on animal breeding. This committee became active again after the war, and Dr (now Professor) F. A. E. Crew was appointed director of research. Later, as a result of liberal benefactions, the scheme was enlarged, and a new and flourishing department of genetics with a large staff of workers was formed in the University of Edinburgh.

In the meantime Ewart turned his attention to the origin and history of feathers in birds, and their relation to scales in reptiles, and the rearing of penguins in the newly formed Zoological Park in Edinburgh gave him an opportunity for obtaining relevant material. He published a paper on the nestling feathers of the mallard in 1921, and this was his last considerable original research.

Ewart was elected a Fellow of the Society in 1879, and served on its Council from 1882 to 1885, 1904 to 1907, and from 1907 to 1912 as a Vice-President. He was awarded the Neill Medal and Prize of the Royal Society of Edinburgh in 1898.

He was elected a Fellow of the Royal Society of London in 1893. On retiring from his Professorship in 1927 he received the honorary degree of LL.D. from the University of Edinburgh. In 1901 Ewart was President of the Zoology Section of the British Association at Glasgow, where he gave an address on *The Experimental Study of Variation.* He was Swiney Lecturer in Geology at the British Museum in 1907, taking as the subject of his lectures equine ancestry.

He died on New Year's Eve, 1933, after a short illness at Penicuik. He leaves a widow, a married daughter, and a son who is a surgeon on the staff of St George's Hospital, London.

J. H. A. and F. H. A. M.

James Haig Ferguson, LL.D., M.D., F.R.C.P.E., F.R.C.S.E., F.C.O.G.

DR HAIG FERGUSON, who died on May 2, 1934, in his seventy-second year, had for some years been the accepted doyen of the obstetrical and gynæcological section of the medical profession in Edinburgh. The son of the Rev. Wm. Ferguson, minister of Fossoway, he was distantly connected on his mother's side with Field-Marshal Earl Haig. He received his early education at the Collegiate School in Edinburgh, and graduated M.B., C.M., in the University in 1884. After two years in resident hospital posts he became private assistant to Dr (later Sir) Halliday Croom in 1886, and the association and friendship thus started determined Haig Ferguson's future line of work. For twenty years he carried on a large family practice, which he had inherited from Croom when the latter restricted himself to consulting work. But his reputation as an obstetrician and gynæcologist grew rapidly during these years, and in 1906, when he was appointed Assistant Gynæcologist to the Royal Infirmary, he gave up his general practice. Seven years previously he had been appointed to the staff of the Royal Maternity Hospital. Early in his career Haig Ferguson had become a Fellow of the Royal College of Physicians, which was the customary procedure for the obstetrical specialist of those days, but as the practice of gynæcology became increasingly surgical he recognised the need of obtaining a higher surgical qualification, and in 1902 he became a Fellow of the Royal College of Surgeons of Edinburgh. Of this College he ultimately became President in 1929 and held office for two years. Dr Haig Ferguson was also actively interested in the foundation, some five years ago, of the British College of Obstetricians and Gynæcologists, of which he became a Foundation Fellow.

Brought up in the tradition that teaching was an essential part of the specialist's work in a medical school such as Edinburgh, he lectured for some years in the Extra-mural School; but it is as a clinical teacher rather than a systematic lecturer that he will be remembered by his former pupils. His wide knowledge of his subject, his practical experience, and his sympathetic consideration for the personal aspect of every patient's case all combined to make him a clinical teacher who could not fail to have lasting influence over his pupils.

For nearly fifty years Haig Ferguson was a Fellow, and on two occasions he was elected President of the Edinburgh Obstetrical Society, to which he contributed many papers, mostly records of cases of unusual interest. Probably his most valuable contribution was on a modification of the axis-traction forceps. The instrument which he devised is perhaps not so scientifically correct as Milne Murray's forceps, but in modern obstetrics the need for accurate axis-traction has largely diminished, and Haig Ferguson's forceps is a very useful and practical instrument with several real advantages over most other patterns. He took an active part in promoting the legislation embodied in the Midwives Act for Scotland, and was a member of the Central Midwives Board from its inception, and Chairman for some ten years up to the time of his death. He gave much time and thought to the important work of this Board, and was scrupulously conscientious also in his service on numerous other public bodies of which he was a member—the Council of the Queen's Institute of District Nursing, the Board of the Royal Hospital for Sick Children, and Donaldson's Hospital, amongst others.

Dr Haig Ferguson was joint author of two books on professional subjects—*A Handbook of Obstetric Nursing*, published in his early years in collaboration with the late Dr W. F. N. Haultain, and *A Combined Textbook of Obstetrics and Gynæcology*, published recently, with colleagues in Edinburgh and Glasgow.

No obituary notice of Dr Haig Ferguson would be adequate without special reference to the unusual attractiveness and nobility of his personal character. His humanity was such as to keep the personal aspect of his patients' troubles ever in the forefront of his mind, and his sympathy was so quick and understanding that all his patients found in him a tower of strength and refuge, a friend as well as a doctor.

He leaves the memory of a man of noble character, of an exemplary devotion to duty and of a personality of quite unusual charm.

He was elected a Fellow of the Society in 1904.

R. W. J.

David Lees, D.S.O., M.A., M.B., Ch.B., D.P.H.

THROUGH the early death of David Lees, who passed away on March 25, 1934, at the age of fifty-three, the medical profession has lost a striking personality and an outstanding leader of opinion and action.

During the World War he served in France as a Regimental Medical Officer to the Welsh Guards and the Irish Guards, and his record of service was marked by high courage and determination in the face of dangers and difficulties. He was awarded the Distinguished Service Order "for Gallantry in Action," and was twice mentioned in dispatches, first during the Third Battle of Ypres, and later in the Battle of Passchendaele.

The initiative and resource which characterised his war service were transferred in 1918 to the investigation and treatment of venereal disease, and he published two papers embodying the results of original work which were the forerunners of a remarkable stream of publications which gave him an international reputation as one of the leading authorities in the world on the subject of venereal disease.

In October 1919 he was appointed Clinical Medical Officer in Venereal Diseases to the Edinburgh Corporation. In establishing subsidiary treatment centres, and in building up this important department of the Public Health service, he displayed such pre-eminent qualities of organising and administrative capacity as to bring him prominently before the civic authorities as a man endowed with an extraordinary capacity for constructive planning. He undoubtedly had a flair for getting things done, and foresight which enabled him to visualise and anticipate future developments.

In May 1926 he was invited by the Secretary of State for the Colonies and by various governing bodies in India to conduct an investigation into the incidence and effect of venereal diseases, and to advise on what measures might be taken to deal with the problems of venereal disease, infant welfare, and maternal mortality. For this investigation, carried out with his usual thoroughness and efficiency, he received the thanks of the Viceroy and the Central Legislative Council.

From 1925 onwards he was annually elected as Chairman of the Medical Advisory Board of the British Social Hygiene Council, and in this capacity he devised and carried out many valuable schemes for the

dissemination of knowledge regarding venereal disease and the best methods to be adopted for combating it.

David Lees was an outstanding pioneer in the campaign against disease. He possessed the necessary driving power and the ability to convince others. He had amazing vitality, superabundant energy, and infectious enthusiasm. His memory is an inspiration, and his work an abiding monument. He left the world a legacy of better health and greater happiness.

He was elected a Fellow of the Society in 1933.

J. G.

Sir Donald MacAlister, of Tarbert, Baronet.

DONALD MACALISTER was born in Perth on May 17, 1854. His school education began in Aberdeen and concluded at the Liverpool Institute. His school successes were phenomenal: he gained every prize he entered for, was first in all England in the Oxford Senior Local Examinations, won half a dozen gold and silver medals, and when he left school gained simultaneously scholarships at Balliol and Worcester Colleges in Oxford, and St John's College, Cambridge. He elected to go to Cambridge, and there, in 1876, he was awarded the Sir John Herschel Prize for Astronomy, and in 1877 was Senior Wrangler and First Smith's Prizeman, and was elected to a Fellowship at St John's. After a term at Harrow as mathematical master, MacAlister turned to medicine, as he had always intended to do. He spent two years studying at St Bartholomew's Hospital, acting at the same time as Lecturer on Natural Philosophy. Survivors of those who were then students have testified to his extraordinary powers as a lecturer, and to his capacity for making things clear even to those possessed of only a rudimentary knowledge of mathematics.

In 1880 he graduated B.Sc., London, and M.B., Cambridge, and spent eight months of the following year working with Professor Ludwig in Leipzig. On his return to Cambridge he was appointed Medical Tutor and Lecturer at St John's, and occupied his spare time by translating into English Ziegler's *Pathological Anatomy*. In 1882 he was appointed Editor of *The Practitioner*, a post he held for twelve years. He graduated M.D. in 1884, and was elected a Fellow of the Royal College of Physicians of London in 1886. The following year he was appointed its Goulstonian Lecturer, and later published his lectures on *The Nature of Fever*. In 1888 he was appointed first Croonian Professor by the College, and delivered a course of lectures on Antipyretics.

In 1889 MacAlister was elected to represent Cambridge University on the General Medical Council in succession to Sir George Humphry on the only occasion when there was a contest for the post. He had the almost unanimous support of the resident members of the medical faculty, and was elected by 194 votes to 139. He remained a member of the Council, later representing the University of Glasgow, until 1933, being President from 1904 to 1931.

From 1881 to 1907, the period of his residence in Cambridge, he took a full and active part in the affairs of the Senate and of the College, where

he was appointed Linacre Lecturer and Tutor. He was elected repeatedly to the Council of the Senate, and for years served as Secretary to that body.

In 1907 MacAlister was chosen by the Crown to succeed Dr Story as Vice-Chancellor and Principal of the University of Glasgow. When he went there he knew little of Scottish academic systems, but within a year he had familiarised himself with the working of Scottish universities, their histories, traditions, and ordinances. He was a great Principal. During his tenure of office over twenty new chairs were established, and the lecturing staff was doubled. The Student Welfare scheme came into being and many new buildings were added. Of all his enterprises, that which lay nearest his heart was the building of the beautiful Memorial Chapel, now one of the chief glories of the University.

When he resigned the Principalship in Glasgow, the University crowned his career by electing him its Chancellor.

MacAlister was an ideal chairman, firm, but always patient and courteous. He had a flair for drafting and understanding ordinances, was quick at seizing points, and amazingly resourceful at finding solutions of difficulties. He undertook and accomplished an astounding amount of work; often done when he was suffering severe pain. He was never strong physically; but his courage and spirit were indomitable, and he held that personal feelings—even pain and extreme weakness—must give way to duty.

He served on the Carnegie United Kingdom Trust, as well as on the Universities' Trust; on the Empire Universities' Bureau; the Imperial College of Science; and on many Commissions, including the Royal Commission on the Civil Service.

MacAlister was created K.C.B. in 1908, and a Baronet in 1924. He was a Deputy-Lieutenant and a Freeman of the City of Glasgow, and a Justice of the Peace for Glasgow and Cambridge. He received honorary degrees from twelve universities in the British Empire, and one from the University of Athens. Other decorations were those of a Commander of the Legion of Honour, and a Cavalier of the Crown of Italy.

He loved travelling and could tell of adventure in many parts of the world. For languages he had a passion. They were his chief recreation, and his book of translated *Echoes* is a *tour-de-force* of bewildering variety.

He was a man of deep religious faith: a staunch Presbyterian. He took an active interest in the transfer of Westminster College from London to Cambridge and in the establishment of St Columba's Church there. He served as an elder in St Columba's for over thirty years.

He was elected a Fellow of the Society in 1917, and died on January 15, 1934.

N. W.

Sir Thomas Muir, Kt., C.M.G., M.A., D.Sc., LL.D., F.R.S.

THOMAS MUIR, who died at Rondebosch, South Africa, on March 21, 1934, was born on August 25, 1844, at Stonebyres, Lanarkshire, and educated at Wishaw Public School and the University of Glasgow, where he came under the influence of Kelvin. Muir showed equal ability in classics and mathematics, but was persuaded by Kelvin to devote himself to the latter. After holding a mathematical tutorship in the University of St Andrews, and enjoying a period of travel on the Continent, he was appointed in 1871 to an assistant lectureship in Glasgow, and in 1874 to be chief mathematical and science master in the Glasgow High School, where for eighteen years he worked with notable success, acquiring a reputation as a great teacher. His powers of organisation attracted the attention of Mr Cecil Rhodes, then Premier at the Cape of Good Hope, who was looking for a suitable Superintendent-General of Education at the Cape: and Muir was duly elected to the post. He reached the Cape in May 1892, and with the enthusiasm of a pioneer pulled together a loose educational system into a systematic whole. He served with conspicuous success until his retirement in 1915: and so far as there is now a broad and liberal spirit in the Cape educational system, it owes its origin predominantly to the work and teaching of Muir.

He initiated three educational reforms. First, the abolishment of the elementary examination in the schools, instead of which he enlarged the usual curriculum with such subjects as domestic economy, woodwork, and drawing. Secondly, the encouragement of the teaching of science, which at first he found to be almost non-existent. Thirdly, the substantial improvement in the training of teachers. He paid careful attention to the erection of properly equipped training institutions and of schools. As a friend has lately remarked, "To whatever little village you go, you will find there no better building than the school."

During these busy years, and more especially in the subsequent nineteen years of retirement from official duties, Muir devoted his leisure with unstinted singleness of purpose to mathematics. His writings upon determinants have already become classical. His first book, the *Treatise on the Theory of Determinants* (Macmillan) appeared in 1882, and a second in 1890. These were followed by the well-known four-volume *History of Determinants* (vol. i, 1906; ii, 1911; iii, 1920; iv, 1923),

together with a supplementary fifth volume (Blackie, 1929). This History has recorded with almost complete success the name, place, and contents of every published book, thesis, and note upon determinants from the earliest records up to 1920. Such a work, in the hands of an unimaginative writer, could be valuable, perhaps, but certainly dull. Muir, who had considerable literary and poetic gifts, made it positively gay! Forty-nine years separate the date of the first list of writings on determinants from the publication of Volume V. Altogether, Muir wrote 307 mathematical papers, continually supplementing and improving existing proofs and adding fresh material. He rendered notable service by making accessible to all mathematicians the pioneering work in algebra of Laplace, Bezout, Cauchy, Schweins, Jacobi, Reiss, Bazin, Sylvester, and Cayley. But Muir had an artistic sense of form, and by his use of a telling notation and of judicious commentary he moulded countless isolated and overlapping propositions into a convincing whole. Muir showed his greatness, not in intuitive discoveries, but in his eminent reasonableness. He reaches through his books a wide public, and has taken an essential part in the algebraic discoveries associated more particularly with Edinburgh, where so much of his work has been published.

Many honours fell to him: in 1874 he became a Fellow of the Royal Society of Edinburgh, and was awarded the Keith Prize in 1884 and again in 1899, and the Gunning Victoria Jubilee Prize in 1916. He was a pioneer and an early President of the Edinburgh Mathematical Society. In 1882 he received the honorary LL.D. degree of the University of Glasgow, and in 1901 was the first recipient of the honorary degree of D.Sc. at the University of the Cape of Good Hope, where he was Vice-Chancellor. In 1892 he became Fellow of the Royal Geographical Society, in 1900 Fellow of the Royal Society: he was given the C.M.G. in 1901, and knighted in 1915.

Muir had wonderful health: until he was eighty he had occasion to consult a doctor only four times and a dentist but twice. A rooted intention to attend a certain meeting in 1925 was a factor in his recovery from a severe illness, after which he completed his fifth volume. From sixty to eighty-four he played tennis, and later took exercise by sawing wood. He had a gentle, kindly manner, a quick smile, and a keen sense of humour. He loved flowers, was a scholarly musician, and had a fine literary sense. To the end he preserved an unclouded brain and an acute and investigating spirit. In a recent letter to a mathematical friend Muir "welcomed the light matrix proofs in contrast to the heavy-footed method of thirty-five years ago": a generous tribute indicative of extraordinary flexibility of mind at an age little short of eighty-seven years.

By a deed of gift Muir has bequeathed his wonderful library of mathematical books and periodicals to the Public Library of South Africa. In 1876 Muir married Margaret Bell of Dumbartonshire, who predeceased him by many years. He is survived by three generations. (See also *Obituary Notices of Fellows of the Royal Society*, No. 3, December 1934.)

H. W. T.

Arthur John Pressland, M.A.

ARTHUR JOHN PRESSLAND, born in 1865, was a scholar of St John's College, Cambridge, graduated as Twelfth Wrangler in 1886, and, after teaching at Heidelberg and Brecon, was for thirty-five years a master at the Edinburgh Academy. He was elected a Fellow of the Society in 1892, was a Fellow also of the Mathematical Society of Edinburgh from 1890 to 1912, and contributed to its *Proceedings*. He made a successful study of Continental languages (including Russian) and of Continental methods of education, and acquired a knowledge of this latter very unusual in this country. He wrote a Report on *Physical Training in Switzerland* for the Royal Commission then sitting in 1902, published a translation of his friend Kerschensteiner's important work, *Education for Citizenship*, in 1911, and was himself the author of *Education and Welfare in Switzerland*. Placed at a disadvantage all through life by defective sight, he possessed a physical vigour and a quiet force of character which enabled him to do an immense amount of valuable work, sometimes in conditions that might have discouraged other men.

In 1925 he retired and settled at Cambridge, where he retained to the last his mental activity and effectual beneficence. An article appeared in an educational magazine last September headed "A New Occupation for Teachers," in which he described what a retired schoolmaster might do, and actually was doing, to help undergraduates. He died in Cambridge, unmarried, on October 8, 1934.

H. J.

Charles Edward Price, J.P.

THE death, on July 7, 1934, of Mr Price, formerly Member of Parliament for the Central Division of Edinburgh, removes from our Roll one who, although he had been a Fellow only since the year 1928, had been of substantial help to the Society at an earlier period, when its interests were critically affected.

Mr Price early in life joined with the late Mr Robert M'Vitie in forming what is now one of the largest firms in Britain, M'Vitie & Price. Retiring at a comparatively early age, he devoted himself to public work, both as a Member of Parliament for almost thirteen continuous years, and as identified with several commercial and philanthropic institutions in Edinburgh and other parts of the Kingdom. When in Parliament he played an important part in the negotiations with the Government of the day in securing for the Society the present premises, when it was dispossessed of its accommodation in the Royal Institution.

In recognition of his parliamentary services the Freedom of the City of Edinburgh was conferred on him in 1919.

J. W.

Christopher Nicholson Johnston (Hon. Lord Sands), Kt., LL.D., D.D.

LORD SANDS was born on October 18, 1857, as the second son of Mr James Johnston, D.L., of Sands. He received his education at the Universities of St Andrews, Edinburgh, and Heidelberg; but mainly at Edinburgh, where he took the degree of M.A. and qualified for the Bar. He was a brilliant student, and had the distinction of being first prizeman in at least two classes, and took a high place in all the others he attended. He was admitted to the Faculty of Advocates in 1880 and practised from that time until he was promoted to the Bench in 1917. He never, however, attained to a leading position at the Bar, even after he took silk in 1902. For this his somewhat hesitating style of pleading and a want of backing in professional circles were largely responsible. His ample leisure in the earlier years enabled him to write manuals on Agriculture and Crofter Legislation, and also an important textbook on *The Ecclesiastical Law of Scotland.* In these departments of law in which he thus specialised he was frequently consulted, and conducted litigations connected therewith. A staunch Conservative at a time when Liberalism was at its high-water mark in Scotland, his active participation in the councils of his party (which included an unsuccessful contest for Parliamentary honours in Paisley in 1892) led to preferment when it came into power on the defeat of Mr Gladstone's First Home Rule Bill, and during the long period that his party thereafter (with one short interregnum) held the reins of office. After some minor appointments as Junior Counsel for certain Government Departments (which were of small value) he became in 1892 an Advocate Depute—the duties of which office he discharged with competence for seven years. In 1899 he resigned his Deputeship on his appointment as Sheriff of Caithness, Orkney, and Shetland, from which he was promoted in 1900 to Inverness, Elgin, and Nairn, and in 1905 to Perth.

Always a loyal and devoted member of the Church of Scotland, of which he became an elder, he took a vigorous part in resisting the attacks of the Liberal Party when Disestablishment became a plank in their programme. Thus in the early 'nineties he wrote a *Handbook of Church Defence*, which proved an invaluable aid to Parliamentary speakers on his side of politics. Partly to this and to the genuine interest which he took in theology, he owed his appointment in 1907 as Procurator of the Church, whose duty it is to advise the General Assembly on matters of law during its sittings, and to act as general adviser to the clergy throughout

the year. This appointment he held till 1918. His publications: *The Seven Churches of Asia* and *The Mission of St Paul to the Roman Empire* and his "Lives" of two eminent ministers, Dr A. Scott and Dr Wallace Williamson, reflect this side of his character. He held a licence to preach, and only a week or so before his death he delivered a characteristic sermon to students at an evening service in St Giles.

Johnston resigned his Sheriffdom in 1916 to become M.P. for the Universities of Edinburgh and St Andrews, but his political career was soon ended on his accepting in 1918 a seat on the Scottish Bench under the judicial title of Lord Sands (there being another Lord Johnston at that time). It was during his tenure of this high office that he earned his chief distinction. Not merely were his judgments marked by an adequate knowledge of law and a strong common sense, but they were characterised by a quaintness of conceit and sometimes by a pungency of criticism that gave them a special distinction. His occasional dissents from his colleagues of the First Division were not infrequently upheld on appeal by the House of Lords.

Although most Judges confine their activities to their judicial duties, Johnston found time for much other work. Thus he acted as Chairman of the Carnegie Trust for Scottish Universities with marked ability until the time of his death, and had, indeed, delivered in London his annual summary of its activities only three weeks before his death. Most of all will he be remembered by the great part he took in the negotiations which culminated after a period of many years in the union of the United Free Church and the Church of Scotland. His knowledge of ecclesiastical law and his sound statesmanlike advice combined with great tact contributed more than any other factor to this supreme achievement. He was for many years chairman of the Philosophical Institution and of the Deaconess Hospital, the new wing of which is to be named after him.

Amongst his literary recreations may be mentioned: *Kinloch Moidart's Dirk*, *Major Owen and other Tales*, *John Blane of Castlehill*—all stories of Scottish romance, mystery, and crime, which form excellent reading.

The University of St Andrews had comparatively early honoured him with the degree of LL.D., and in 1928 the University of Edinburgh conferred on him the degree of D.D.

He was elected a Fellow of this Society in 1925, served on its Council from 1929 to 1932, and from 1932 to 1934 as a Vice-President.

On February 26, 1934, Johnston passed away after a short illness. He had married, in 1898, Agnes W. Dunn, daughter of Mr I. L. Dunn, of Dunmullin, by whom and by two sons and two daughters he is survived.

E. T. S.

Sir Arthur Schuster, F.R.S.

ARTHUR SCHUSTER was born in Frankfurt-on-Main on September 12, 1851, of a wealthy banking family, but emigrated to Manchester with his parents in boyhood. He remained closely connected with Manchester throughout most of his active life, for he occupied first a chair in applied mathematics from 1881 to 1888, and then succeeded Balfour Stewart as Professor of Physics, holding this chair till he retired in 1907. This was the period during which the English provincial universities were expanding, and Schuster took an important part in the development.

Schuster's chief period of scientific activity fell in the interregnum between the older discoveries of the era of Maxwell and the newer of radioactivity and the electron. This was a curiously stagnant period in the history of physics, and, though he made many fine contributions to knowledge, there is no great discovery to his name; yet the record of his work shows that he was definitely a precursor of the new physics rather than an elaborator of the old. Perhaps his most noteworthy feat was to have made the first determination of that important physical quantity e/m; but the time was not ripe and he explained away the result he obtained, making it plausible to believe that the m was the mass of an atom, instead of the much more startling value thousands of times lighter, the mass of the electron. He also had a great interest in geophysics, and made important studies in meteorology and terrestrial magnetism. In this connection he was closely connected with the establishment of the Eskdalemuir Observatory.

He was elected an Honorary Fellow of the Society in 1916, and died on October 14, 1934. (See *Obituary Notices of Fellows of the Royal Society*, No. 3, December 1934.)

C. G. D.

James Young Simpson, M.A., D.Sc., D.Jur.

THE death of Professor J. Y. Simpson on May 20 last removed a distinguished citizen from Edinburgh and an earnest thinker from the ranks of literature. He had returned from a lecturing tour in America in excellent spirits and apparently in normal health, but two days later he was suddenly struck down by illness, and after four more days he passed away without regaining consciousness.

Simpson came of notable ancestors, and was worthy of his heritage. He was the eldest son of Sir Alexander R. Simpson and of a daughter of Barbour of Bonskeid. Born in 1873, he was educated at George Watson's College and then at the University and New College of Edinburgh. Under the inspiration of Henry Drummond, whose Chair he was afterwards (1904) to be called to fill, he made Biology his special field of study, and in 1899 he was appointed to the Lectureship in Natural Science in the Free Church College at Glasgow.

Simpson was elected a Fellow of this Society in 1900, and served on the Council from 1922 to 1925. The results of his observations on the fission of ciliate protozoa were published in the *Proceedings* in 1901 and in *Biometrika*, 1902.

In 1901 the University of Edinburgh conferred on him the degree of D.Sc. Thereafter, appreciation of his hard and patient work was evidenced in his expanding influence.

His wider influence was gained by activity in two different fields which, however, were not so far apart as they appeared on the surface to be. On the one hand, his published works, especially *The Spiritual Interpretation of Nature*, and then its sequel, *Man and the Attainment of Immortality*, established his reputation over wide circles in the English-speaking world and even beyond it. On the other hand, his intimate knowledge of Russia and his official post-war work in the adjustment of frontiers between Estonia, Latvia, and Lithuania made him a popular figure in those lands, and won a good name for him as a wise and capable arbiter and administrator. But his science and his politics were more closely linked than might appear, for his scientific interest gained for him an entrance into many Eastern European doors which were apt to be closed to a more ordinary foreigner.

There can be no doubt at all as to the interest which dominated

Simpson's mind and gave unity to his many diverse activities. He never swerved from his early ambition to continue the work of Henry Drummond in doing something to heal the breach between Science and Religion. He was essentially a frontier man. His arbitration work in the Baltic countries was a parable of his mind. His thoughts moved in the borderland between Science and Religion, and it was his intellectual ambition to assist in the work of arbitration there.

That Nature cannot be interpreted other than spiritually was an early conviction with Simpson, and it grew even stronger with the years. He hailed with delight the recognition of the spiritual background of Nature by mathematical astronomers like Jeans and Eddington. He himself claimed no competence in Modern Physics, but he interested himself more and more in that bewildering field during his later years, and attained to a quite adequate idea of the lie of the land. He was thus more and more in demand as a lecturer on the relation of Science to Religion, and it is more than possible that his last lectures, delivered during his recent tour in America, took more out of him than he knew, and hastened on his physical collapse.

"J. Y.," as his friends named him, was a very friendly man. In every part of the world there are those who have good reason to be grateful to him and his charming wife for the abounding hospitality of 25 Chester Street. Nor did he lack appreciation of his own Edinburgh, nor fail to rejoice in its appreciation of him. Whether in his Chair in New College, or in the general cause of Education, or in his Church, or in the promotion of any worthy movement, or as one of the most skilful among the Royal Company of Archers, he gave liberally of mind and heart and life to his own city.

D. L.

Duncan M'Laren Young Sommerville, M.A., D.Sc.

PROFESSOR SOMMERVILLE, the son of the Rev. Dr James Sommerville, was born in 1879 in Rajputana and died on January 31, 1934, in New Zealand. After receiving an early education at Perth Academy he entered the University of St Andrews, where his mathematical and scientific ability soon became apparent. In 1899 he obtained a Ramsay and in the following year a Bruce Scholarship: in 1905 he was appointed Lecturer in the Mathematics Department at St Andrews, a post which he filled until in 1915 he became Professor of Pure and Applied Mathematics in Victoria College, Wellington, New Zealand. His scholarly and unobtrusive demeanour as a young lecturer won the admiration of his colleagues and pupils in St Andrews, where his teaching left a permanent mark. While he was essentially a geometer he had considerable interests in other sciences; and it is noteworthy that the classes which he chose to attend in his fourth year of study were in Anatomy and Chemistry. Crystallography in particular appealed to him; and doubtless these subjects influenced his geometrical concepts and led Sommerville to ponder over space-filling figures, and gave an early impetus to thoughts in a field which he made peculiarly his own. Beneath his outward shyness considerable talents lay concealed: his intellectual grasp of geometry was balanced by a deftness in making models, and on the æsthetic side by an undoubted talent with the brush. In the course of years he produced a pleasing collection of water-colour sketches of New Zealand scenery.

His mathematical work falls naturally into two parts: that of the teacher and that of the investigator. His textbooks, which have appeared at regular intervals, are a valuable link between the old and the new era in the teaching of geometry at college. They are the *Elements of Non-Euclidean Geometry* (1914), *Analytical Conics* (1924), *Introduction to the Geometry of* n *Dimensions* (1929), and the recent *Three-Dimensional Geometry*, the appearance of which he did not live to see. All are characterised by a variety of algebraic treatment and a wealth of illustrations and examples, but nowhere does technical manipulation outrun the geometry. The first of these, a provocative little book, appeared at a time when metrical systems alternative to that of Euclid were known only to the few. It is not surprising that such a teacher carried through-

out his life the esteem and appreciation of his students. One of his most distinguished pupils, A. C. Aitken, writes of the critical time in his own student days when the University of Otago was temporarily without a Professor of Mathematics, and how willingly Sommerville filled the gap by weekly correspondence. The written solutions and comments went far beyond what was necessary for mere elucidation.

Beginning in 1905, Sommerville wrote over thirty original papers and notes which have been published in well-known journals at home and abroad. The first, entitled "Networks of the Plane in Absolute Geometry" (*Proc. Roy. Soc. Edin.*, vol. xxv, 1905) is typical of the sequel. The main theme is that of combinatory geometry, exemplified by a systematic investigation of "The Division of Space by Congruent Triangles and Tetrahedra" (1923) in the same journal, and extended to *n* dimensions (*Rend. Circ. Mat. Palermo*, vol. xlviii, 1924, pp. 9–22). Out of this grew the work upon the relations connecting the angle sums and volume of a polytope in space of *n* dimensions (*Proc. Roy. Soc.*, 1927).

Sommerville was ever ready to apply his special gifts to unusual examples, as in his analysis of preferential voting and a highly original analysis of the musical scale. His was a life of unsparing activity, and the fruits of his work will abide. There has passed from Scotland one who had already become her leading geometer of the present century.

He was elected a Fellow of the Society in 1911.

H. W. T.

Swale Vincent, M.D., D.Sc., LL.D., F.R.S.C.

PROFESSOR SWALE VINCENT was born on May 24, 1868, at Birmingham, where he was educated at King Edward VI Grammar School and the University, then Mason College. After graduation he went to Heidelberg to study under Kossel, and returned to become Demonstrator in Physiology in Birmingham. Here in 1896 he published his first scientific paper, which gave evidence of his interest in the physiology of the lower vertebrates; an interest he always retained. He was attracted by the work of Oliver and Schäfer upon adrenaline, and in the field of endocrinology he found his life's work. From 1897 to 1904 he held positions in University College, London, Cardiff, and Edinburgh, and at the first and last of these he was closely associated with Schäfer and his co-workers. In 1904 he was appointed Professor of Physiology in the University of Manitoba and remained there until 1920. There he did much valuable work, not only in founding and building up a department, but also in setting up a standard of enthusiasm and high achievement that made a definite impression upon the university as a whole. His services were recognised by the conferment of an honorary LL.D. He returned to England in 1920 to fill the newly created chair of Physiology in Middlesex Hospital, from which he retired in 1930.

He was elected a Fellow of the Society in 1910.

He was an indefatigable and critical worker, and made many and noteworthy contributions to his science. Forthright in his life and speech, he did not suffer fools gladly, and would not countenance slipshod work or muddle-headedness in his pupils. To a casual acquaintance his shyness often made him appear brusque, but his friends found in him a charming companion with wide interests, and his colleagues a staunch supporter of any project that had as its object the welfare of science or of the University. His knowledge and love of music were outstanding.

He died on December 31, 1933, and is survived by his wife and two daughters.

C. H. O'D.

FREDERICK ALEXANDER BLACK, Solicitor, Inverness, was interested in astronomy, and published several books. During the War he was on Sir Auckland Geddes's staff, doing duty at Dumbarton and Dundee.

He was elected a Fellow of the Society in 1907, and died on September 9, 1934.

JAMES BELL DOBBIE, late of the Royal Bank of Scotland, was deeply interested in ornithology; his extensive collection of British and foreign eggs was purchased by the Royal Scottish Museum.

He was elected a Fellow of the Society in 1897, and died on June 26, 1934.

SIR WILLIAM BATE HARDY, Kt., M.A., F.R.S., Director of Food Investigation in the Department of Scientific and Industrial Research, was born in Erdington on April 6, 1864.

He was elected an Honorary Fellow of the Society in 1930, and died on January 23, 1934. (See *Obituary Notices of Fellows of the Royal Society*, No. 3, December 1934.)

SIR ALEXANDER CRUIKSHANK HOUSTON, K.B.E., LL.D., F.R.S., Director of Water Examinations, Metropolitan Water Board, author of numerous reports and papers on Public Health subjects, was born on September 18, 1865.

He was elected a Fellow of the Society in 1897, and died on October 29, 1933. (See *Obituary Notices of Fellows of the Royal Society*, No. 3, December 1934.)

ANDREW WILLIAM KERR, F.S.A.Scot., was one of the originators and the first Secretary of the Institute of Bankers in Scotland. He was also Treasurer for a period of years of the Scottish Natural History Society. He was the author of *A History of Scottish Banking* (1884), and other volumes.

He was elected a Fellow of the Society in 1908, and died on October 1, 1934.

ALEXANDER VEITCH LOTHIAN, M.A., B.Sc., was elected a Fellow in 1898, and died on November 30, 1933.

DAVID CLARK THOMSON MEKIE, M.A., Ph.D., lately Headmaster of Darroch Intermediate School, Edinburgh, was keenly interested in geography and racial and labour problems, and wrote on these subjects. He was a Fellow and an active Member of Council of the Royal Scottish Geographical Society.

He was elected a Fellow of this Society in 1926, and died on February 22, 1934, aged sixty.

DUKINFIELD HENRY SCOTT, M.A., LL.D., F.R.S., formerly Honorary Keeper of the Jodrell Laboratory, Royal Botanic Gardens, Kew, was born in London on November 28, 1854.

He was elected an Honorary Fellow of this Society in 1930, and died on January 29, 1934. (See *Obituary Notices of Fellows of the Royal Society*, No. 3, December 1934.)

ROBERT SOMERVILLE, B.Sc.(Edin.), Principal Science Master in Dunfermline High School, was one of the founders of the Dunfermline Naturalists' Society, and its Honorary Secretary for more than thirty years. In addition to contributing articles to scientific and other publications, he was the author of a volume entitled *Dunfermline Sketches and Notes*.

He was elected a Fellow of the Society in 1910, and died on September 14, 1934, aged sixty-three.

APPENDIX.

CONTENTS.

PROCEEDINGS OF THE STATUTORY GENERAL MEETING

Beginning the 151st Session, 1933–1934.

At the Statutory General Meeting of the Royal Society of Edinburgh, held in the Society's Rooms, 24 George Street, on Monday, October 23, 1933, at 4.30 P.M.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair,

the Minutes of the Statutory Meeting held on October 24, 1932, were read, approved, and signed.

The GENERAL SECRETARY submitted the following Report:—

GENERAL SECRETARY'S REPORT, OCTOBER 23, 1933.

On January 9, 1933, by request of the Council, an "Experimental Demonstration of the Measurement of the Diffusion Coefficients of Bromine-Hydrogen and Bromine-Carbon Dioxide" was given by Drs J. E. MACKENZIE and H. W. MELVILLE, and an address (with demonstration) was delivered by Professor J. G. GRAY, D.Sc., on "Self-erecting Gyrostats." On May 1, 1933, in terms of the award of the JAMES SCOTT PRIZE, and by request of the Council, Professor Dr ARNOLD SOMMERFELD, For. Mem. R.S., gave an address on "Ways to the Knowledge of Nature."

41 papers were read, as compared with 40 in the previous session. The papers were divided among subjects as follows:—Mathematics, 5; physics, 3; chemistry, 2; geology and mineralogy, 5; palæontology and palæobotany, 5; botany, 2; zoology, 9; human genetics, 4; animal genetics, 2; physiology, 3; and anatomy, 1. 14 papers have been published, or are being published in the *Transactions*, and 20 in the *Proceedings*. 6 papers were read but have not yet been submitted in final form, and 1 has been withdrawn. Several papers have been declined as unsuitable for publication by the Society.

The Society has lost by death 24 Fellows and 2 Honorary Fellows; 3 Fellows have resigned, and 1 has been removed from the Roll of Fellows. 36 Fellows and 6 Foreign and 2 British Honorary Fellows have been elected. Dr WILLIAM HOPE FOWLER, it is regretted, has died since his election.

Invitations were received, and the Society was represented as follows on the occasions mentioned:—

1. Deutsche Gesellschaft für Natur- u. Völkerkunde Ostasiens in Tokyo. 60th Anniversary, March 22, 1933. Professor A. TANAKADATE presented address.
2. Warsaw, Society of Sciences and Literature. Celebration, November 23, 1932. Letter sent.
3. Entomological Society of London. 100th Anniversary in London, May 3 and 4, 1933. Sir T. HUDSON BEARE and Dr R. STEWART MACDOUGALL presented address.
4. International Geological Congress at Washington, July 22 to 29, 1933. Sir JOHN FLETT, F.R.S., and Professor W. T. GORDON, D.Sc.

It has been decided that the first award of the DAVID ANDERSON-BERRY PRIZE for the best recent work on the nature of X-Rays in their therapeutical effect on human diseases should be made in the summer of 1935.

The GUNNING VICTORIA JUBILEE PRIZE for the period 1928–1932 was awarded to Sir JAMES WALKER, F.R.S.

The MAKDOUGALL-BRISBANE PRIZE for the period 1930–1932 was awarded to Dr A. C. AITKEN and the JAMES SCOTT PRIZE to Professor Dr ARNOLD SOMMERFELD, For. Mem. R.S.

The BRUCE-PRELLER LECTURE will be delivered by Professor C. H. LANDER, C.B.E., on the "Liquefaction of Coal."

The British Expedition in connection with the Polar Year 1933, in the organisation of which the Society occupies an exceptional position, has been conducted with conspicuous success at Fort Rae in Canada.

Professor T. J. MACKIE will represent the Royal Society of Edinburgh and the University of

Edinburgh, jointly, for a further term of three years, as from February 1933, on the India Office Committee for the recruitment of medical research workers.

In view of the present adverse exchanges and the high cost of German Periodicals, the Council decided to discontinue, in the meantime, the following journals:—Neues Jahrbuch für Mineralogie u. Paläontologie (all sections); Centralblatt für Mineralogie, Geologie u. Paläontologie (A and B); Zeitschrift f. Kristallographie, Mineralogie u. Petrographie (A *only*); and Zentralblatt f. Bakterologie, Parasitenkunde u. Infektionskrankheiten (all sections). All these journals are accessible elsewhere in Edinburgh.

During the session additional steel shelving has been added in the Front Reading Room (Street Floor), the Gallery has been slightly extended, and a lighter steel stair erected. Painting and some other alterations have also been carried out on the North Wall of the Lecture Room, to the improvement of its appearance.

A number of new publications were added to the Library by exchange and purchase during the session.

The Assistant Librarian, Mr R. J. B. MUNRO, has been placed under the Federated Superannuation System for Universities.

The acknowledgment of the Society is due to the Carnegie Trust for the Universities of Scotland for grants to authors towards the cost of the illustrations of papers published in the *Transactions* and *Proceedings*, amounting to £154, 18s. 11d.; to the University College, Dundee, for £1, 10s. 4d. towards the cost of the illustration of Mr W. F. HARPER'S paper in the *Proceedings*; to Dr A. G. HUTCHISON for £15 towards the cost of the illustration of his paper in the *Transactions*; and to the Royal Society of London for a sum of £250 from the Government Publication Grant in aid of the cost of publishing the Society's *Transactions* and *Proceedings* during the session 1932–1933.

TREASURER'S REPORT:—

The TREASURER stated that, as was the case last year, there was no outstanding feature with regard to finance. The Accounts of last year showed a surplus of £20, 14s. 1½d., while this year they showed a deficiency of £62, 9s. 9d.

The PRESIDENT nominated as Scrutineers, Sir HAROLD STILES and Dr ALEXANDER LAUDER.

The Ballot for the Election of Office-Bearers and Council was then taken.

Dr J. E. MACKENZIE moved the adoption of the Reports and the reappointment of Messrs LINDSAY, JAMIESON & HALDANE, C.A., as auditors for the ensuing session. These motions were approved.

The Scrutineers reported that the Ballot Papers were in order, and the PRESIDENT declared that the following Office-Bearers and Council had been duly elected:—

Emeritus Professor Sir E. A. SHARPEY-SCHAFER, M.D., D.Sc., LL.D., F.R.S., President.

J. B. CLARK, M.A., LL.D., J.P. Professor JAMES RITCHIE, M.A., D.Sc. Principal Sir THOMAS H. HOLLAND, K.C.S.I., K.C.I.E., D.L., D.Sc., LL.D., F.R.S. The Hon. LORD SANDS, Kt., LL.D., D.D. Professor C. G. DARWIN, M.A., F.R.S. Professor R. A. SAMPSON, M.A., D.Sc., LL.D., F.R.S.	Vice-Presidents.

Professor J. H. ASHWORTH, D.Sc., F.R.S., General Secretary.

Professor F. A. E. CREW, M.D., D.Sc., Ph.D. Professor JAMES P. KENDALL, M.A., D.Sc., F.R.S.	Secretaries to Ordinary Meetings.

JAMES WATT, W.S., LL.D., Treasurer.

Professor D'ARCY W. THOMPSON, C.B., D.Litt., LL.D., F.R.S., Curator of Library and Museum.

MEMBERS OF COUNCIL.

Professor P. T. HERRING, M.D., F.R.C.P.E.
Professor THOMAS M. MACROBERT, M.A., D.Sc.
Professor GODFREY H. THOMSON, D.Sc., Ph.D.
MALCOLM WILSON, D.Sc., A.R.C.S.
Professor E. B. BAILEY, M.C., M.A., F.R.S.
Professor J. C. BRASH, M.C., M.A., M.D.
Professor A. J. CLARK, M.C., B.A., M.D., F.R.S.
Professor A. G. OGILVIE, M.A., B.Sc.
Professor E. M. WEDDERBURN, M.A., D.Sc., LL.B., W.S.
Lt.-Col. A. G. M'KENDRICK, M.B., D.Sc., F.R.C.P.E.
Emeritus Professor JAMES MACKINNON, M.A., Ph.D., LL.D.
Professor WILLIAM PEDDIE, D.Sc.

The PRESIDENT thanked the Scrutineers for their services.

The Public were then admitted.

The PRESIDENT, in the course of his remarks, referred to the losses of the Society by the deaths of Ordinary and Honorary Fellows, details of which may be found in the Obituary Notices, already published in the *Proceedings*.

In introducing Professor C. H. LANDER, C.B.E., the PRESIDENT said:—

It is common knowledge that the production of oil from coal, by hydrogenation, is one of the most important industrial problems in this country at the present moment. The theory of the liquefaction of coal is well understood—the difficulty is so to adapt the process that it can be worked on a large scale and at a profit. This problem has been intensively studied by the Fuel Research Board of the Department of Scientific and Industrial Research during the past decade, and the promise of conversion of theory into practice recently announced has been rendered possible largely by the labours of this Board, of which Professor LANDER was director from 1923 to 1931. His improvements in the construction of the stills used in low-temperature carbonisation may be particularly mentioned. Professor LANDER has served with distinction on many other government committees connected with the coal industry, and since 1931 has held the chair of Mechanical Engineering at the Imperial College.

Professor C. H. LANDER, C.B.E., at the request of the Council and in terms of the BRUCE-PRELLER LECTURE FUND, then delivered an address, with Lantern Illustrations, on "The Liquefaction of Coal."

The PRESIDENT cordially thanked Professor LANDER for his address.

PROCEEDINGS OF THE ORDINARY MEETINGS, Session 1933–34.

FIRST ORDINARY MEETING.

Monday, November 6, 1933.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

A vote of thanks to Professor R. A. SAMPSON for his services to the Society as its Secretary during the past ten years was proposed by Professor C. G. DARWIN, seconded by Professor J. H. ASHWORTH, and carried unanimously with acclamation.

The following Communications were submitted:—

1. The Cruciform Muscle of Lamellibranchs. By ALASTAIR GRAHAM, M.A., B.Sc. Communicated by Professor J. H. ASHWORTH, F.R.S. *Proc.*, vol. 54, pp. 17–30.
2. The Developmental Stages of *Euchæta norvegica*, Boeck. By A. G. NICHOLLS, Ph.D. Communicated by Professor J. H. ASHWORTH, F.R.S. *Proc.*, vol. 54, pp. 31–50.
3. The Weight and Chemical Composition of *Euchæta norvegica*, Boeck. By A. P. ORR, B.Sc. Communicated by Professor J. H. ASHWORTH, F.R.S. *Proc.*, vol. 54, pp. 51–55.
4. On the Morphology and Cytology of *Puccinia Prostii*, Moug. A Micro-form with Pycnidia. By IVAN M. LAMB, B.Sc. Communicated by Dr MALCOLM WILSON. *Trans.*, vol. 58, pp. 143–162.

The following Papers were read by title:—

5. Studies on the Reproductive System in the Guinea-Pig: Post-partum Repair of the Uterus, and the Associated Appearances in the Ovaries. By T. NICOL, M.B., Ch.B., F.R.C.S.E. *Trans.*, vol. 57, pp. 765–775.
6. On the Fitting of Polynomials to Weighted Data by Least Squares. By A. C. AITKEN, M.A., D.Sc. *Proc.*, vol. 54, pp. 1–11.
7. On Fitting Polynomials to Data with Weighted and Correlated Errors. By A. C. AITKEN, M.A., D.Sc. *Proc.*, vol. 54, pp. 12–16.
8. Studies on the Physiology of Reproduction in the Ewe: I. The Symptoms, Periodicity, and Duration of Œstrus. II. Changes in the Vagina and Cervix. By R. GRANT, B.Sc., Ph.D. Communicated by Professor F. A. E. CREW, M.D. *Trans.*, vol. 58, pp. 1–47.

SECOND ORDINARY MEETING.

Monday, December 4, 1933.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

At the request of the Council an Address was given on "The British Polar Year Expedition to Fort Rae, 1932–1933" by JAMES M. STAGG, M.A., B.Sc. (Meteorological Office, Air Ministry, London), Leader of the Expedition.

A vote of thanks to Mr STAGG was proposed by Dr A. CRICHTON MITCHELL and seconded by Professor R. A. SAMPSON.

THIRD ORDINARY MEETING.

Monday, January 8, 1934.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

Dr DAVID RUSSELL signed the Roll of Fellows and was inducted by the President.

The President, from the Chair, proposed that the Constitution of the Society should be altered as follows:—

LAW I.—For "fifty-six" read "sixty-six," for "twenty" read "twenty-two," and for "thirty-six" read "forty-four,"

so that the sentence corrected would read as follows:—

"The number of Honorary Fellows shall not exceed sixty-six, of whom not more than twenty-two may be British subjects, and not more than forty-four subjects of Foreign States."

The President further proposed:—

"That in view of the completion of its 150th year the Society may elect Honorary Fellows at any Ordinary Meeting in the year 1934, notwithstanding the provisions of Law IX as to the Meeting at which such election shall take place."

The following Communications were submitted:—

1. Notes on the Kidston Collection of Fossil Plant Slides. No. III.—Some Points in the Anatomy of *Sigillaria elegans* Brongniart. No. IV.—On the Nature of the Corona and its Relationship to the Leaf Traces in the Lepidodendreæ and Sigillariæ, with special reference to certain "Diploxyloid" Specimens in the Kidston Collection. By MARY G. CALDER, Ph.D. Communicated by Dr S. WILLIAMS. *Trans.*, vol. 58, pp. 49–62.

2. Bishop James Kennedy: An Anthropological Study of His Remains. By Professor DAVID WATERSTON, M.A., M.D., F.R.C.S.E. *Trans.*, vol. 58, pp. 75–111.

3. Studies on the Physiology of Reproduction in the Ewe. III.—Gross Changes in the Ovaries. By R. GRANT, B.Sc., Ph.D. Communicated by Professor F. A. E. CREW, M.D. (Read by title.) *Trans.*, vol. 58, pp. 1–47.

FOURTH ORDINARY MEETING.

Monday, February 5, 1934.

Professor C. G. Darwin, F.R.S., Vice-President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

The Vice-President intimated that H.R.H. THE DUKE OF YORK had graciously consented to be nominated for election as an Honorary Fellow.

The alterations in Law I, and the Resolution as printed on the Billet of Meeting (see below) which were formally proposed by the President at the last Ordinary Meeting, were placed before the Society for approval. The Vice-President formally proposed from the Chair that these alterations be approved. The Meeting signified its approval.

(*a*) Alterations in Law I:

For "fifty-six" read "sixty-six," for "twenty" read "twenty-two," and for "thirty-six" read "forty-four."

The sentence would therefore read as follows:—

"The number of Honorary Fellows shall not exceed sixty-six, of whom not more than twenty-two may be British subjects, and not more than forty-four subjects of Foreign States."

(*b*) Resolution:

"That in view of the completion of its 150th year the Society may elect Honorary Fellows at any Ordinary Meeting in the year 1934, notwithstanding the provisions of Law IX as to the Meeting at which such election shall take place."

At the request of the Council an Address was delivered on "The Psychology of Crime and Criminals, with special reference to Measures for Reformation," by R. A. FLEMING, M.A., M.D., LL.D.

FIFTH ORDINARY MEETING.

Monday, March 5, 1934.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

The President read a letter from the Secretary of State for Scotland in which it was intimated that HIS MAJESTY THE KING had been graciously pleased to grant his patronage to the Society.

The President proposed from the Chair that H.R.H. THE DUKE OF YORK be elected an Honorary Fellow. The Meeting unanimously agreed that he be elected.

The Ballot for Fellows then took place. The President nominated Dr L. DOBBIN and Dr J. E. MACKENZIE to act as Scrutineers. The following were duly elected:—

DAVID BAIN, PATRICK BROUGH, IVAN DE BURGH DALY, FRANK FRASER DARLING, DAVID RUTHERFORD DOW, WILLIAM LEONARD EDGE, IVOR MALCOLM HADDON ETHERINGTON, GEORGE FRASER, JOHN GLAISTER, ROBERT MACLAGAN GORRIE, DAVID HALDANE, JOHN VERNON HARRISON, JOHN JEFFREY, SIR WILLIAM CAMPBELL JOHNSTON, R. CRANSTON LOW, MAGNUS MOWAT, WALTER GEORGE ROBERTSON MURRAY, ALEXANDER ROBERT NORMAND, RUDRENDRA KUMAR PAL, HAROLD JAMES PLENDERLEITH, DANIEL EDWIN RUTHERFORD, HAROLD KEITH SALVESEN, MATTHEW SYDNEY THOMSON, JOHN WEIR, WILLIAM WHYTE, WILLIAM PERSEHOUSE DELISLE WIGHTMAN, BERTRAM MARTIN WILSON, ARTHUR WINSTANLEY.

The President announced that the Council of the Society had awarded the KEITH PRIZE for the period 1931–1933 to A. CRICHTON MITCHELL, D.Sc., for his Paper on "The Diurnal Incidence of Disturbance in the Terrestrial Magnetic Field," published in the *Transactions* within the period of the award.

The NEILL PRIZE for the period 1931–1933 to G. W. TYRRELL, A.R.C.S., D.Sc., F.G.S., for his contributions to the Geology and Petrology of Sub-Arctic and Sub-Antarctic Lands.

The President announced that these prizes would be presented on July 2, 1934.

The President referred to the loss that the Society had endured through the lamented death of LORD SANDS.

The following Communications were submitted:—

1. The Metamorphic Rocks of North-East Antrim. By Professor E. B. BAILEY, M.C., F.R.S., and W. J. MCCALLIEN, D.Sc. *Trans.*, vol. 58, pp. 163–177.
2. The Spermatogenesis of the Axolotl (*Amblystoma tigrinum*). By ROBERT CARRICK, B.Sc. Communicated by Professor J. GRAHAM KERR, F.R.S. *Trans.*, vol. 58, pp. 63–74.
3. Spermatogenesis in *Drosophila pseudo-obscura* Frol. II.—The Cytological Basis of Sterility in the Hybrid Males of Races A and B. By P. CH. KOLLER, D.Sc. Communicated by Professor F. A. E. CREW, M.D. *Proc.*, vol. 54, pp. 67–87.
4. Studies on the Reproductive System in the Guinea-Pig: Observations on the Ovaries, with special reference to the Corpus Luteum. By THOMAS NICOL, M.B., Ch.B., F.R.C.S.E. (Read by title.) *Proc.*, vol. 54, pp. 56–66.

COMMEMORATION OF COMPLETION OF 150TH YEAR.

SIXTH ORDINARY MEETING.

Monday, May 7, 1934.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Meeting were taken as read, and signed.

The President, having announced that the Meeting was in commemoration of the completion of the 150th year of the Society, continued as follows:—

THE ROYAL SOCIETY OF EDINBURGH was incorporated by a Royal Charter granted by George III in 1783. But its formation was led up to by other associations of literary and scientific men, one of which was the *Rankenian Club*, so-called after the tavern (Rankine's) in which the meetings were held, another the *Select Society for Literary Discussion and Philosophical Inquiry*,

and a third the *Society for Improving Natural Knowledge*, the first President of which was James Douglas, Earl of Morton, who in 1764 became the President of the Royal Society of London. This Society between 1754 and 1771 published three volumes of *Essays and Observations, Physical and Literary*. In the meantime a Medical Society had been established in 1731, which in 1733 published six volumes of *Medical Essays and Observations*. This Society was eventually amalgamated with the Society for Improving Natural Knowledge under the title of the *Philosophical Society of Edinburgh*. It was then decided to obtain a Charter for the amalgamated Society similar to that which had been granted by Charles II to the Royal Society of London. In the list of notable persons who were instrumental in obtaining the Charter we find the name of the Lord Provost of Edinburgh—a fact to be especially recalled on the present occasion when, for the first time since the incorporation of the Society, the Chief Magistrate and City Council are associating themselves with us in the celebration of our 150th anniversary by giving a Reception in honour of that event.

The Society was originally constituted by the assumption of all members of the old Philosophical Society as Ordinary Fellows of the new Royal Society, the Judges of the Supreme Court and a number of other eminent gentlemen being also invited to join it. Although the Professors of the University of Edinburgh were largely instrumental in the promotion of the Charter, the original Fellowship embraced many members of the Senatus of the Universities of St Andrews, Aberdeen, and Glasgow. Other Fellows having been elected under the Statutes, there were in the first year as many as 173 Fellows, of whom 102 were resident and 71 non-resident. They were divided into two classes, *Physical* and *Literary*, and in the early volumes of the *Transactions* the papers were also thus grouped. But after four volumes had appeared it was obvious that the *Physical* (Scientific) side would far exceed and dominate the *Literary*, and the distinction was given up.

Under the Charter the Society had the right of electing eminent men, who might be foreigners, as Honorary Fellows. This right they exercised already in the first year, Buffon (naturalist), Benjamin Franklin (physicist), and Camper (anthropologist) being in the list. They were followed before long by Werner (geologist), Laplace, Lagrange, Biot, Ampère, Berzelius, and Arago (physicists and chemists), by Cuvier, de Candolle, Blumenbach, and Humboldt, representing various branches of science, and by Chantrey (sculptor) and Goethe (poet and naturalist): the last two in 1822 and 1823 respectively, during the Presidency of Sir Walter Scott. Henry Raeburn had been elected as an Ordinary Fellow in 1819. Sir Walter had been a Fellow since 1800—he is there entered as Mr Walter Scott: he remained President until his death in 1832. His predecessors were the Duke of Buccleuch (1783–1812) and Sir James Hall the geologist (1812–1820). Sir Walter was succeeded by Sir Thomas Makdougall-Brisbane, who occupied the Chair from 1832 to 1860 (28 years). It was then resolved that a President's period of office should not exceed five years: this is still the practice of the Society.

In the course of its first hundred years a large number of distinguished men have been connected with the Society, especially on the scientific side. Amongst the mathematicians and physicists of that period we find the names of Charles Babbage, James Thomson, George Gabriel Stokes, Arthur Cayley, William Thomson (Lord Kelvin), David Brewster, James Forbes, James Clerk Maxwell, Balfour Stewart, P. G. Tait, Lord Rayleigh, and the astronomers J. F. W. Herschel and Piazzi Smyth; amongst the chemists, Joseph Black, Thomas Charles Hope (the discoverer of Strontium), Thomas Graham, Thomas Andrews, and Thomas Anderson; amongst the geologists, James Hutton, James Hall, John Playfair, James Forbes, Archibald Geikie, James Geikie, B. N. Peach, John Horne, Robert Kidston, and J. W. Gregory; amongst the meteorologists, John Aitken and Alexander Buchan; amongst biologists, Edward Forbes, Wyville Thomson, John Murray, John Hutton Balfour, Bayley Balfour, James Cossar Ewart, and W. C. M'Intosh; amongst the anatomists, the Monros, John Goodsir, William Turner, and David Cunningham; amongst the physiologists, Charles Bell, John Davy, and John G. M'Kendrick; and last, but by no means least, too numerous for individual mention, many physicians and surgeons who have made important advances in their sciences, but among whom two names are pre-eminent, and cannot be omitted from any list of great discoverers in Medicine and Surgery, James Simpson and Joseph Lister.

The President then announced that, in celebration of the occasion, the Council of the Society had nominated for election as Honorary Fellows the following eminent scientific men:—

Foreign: Björn Helland-Hansen, Geophysical Institute, Bergen; Bernardo Houssay, Professor of Physiology, National University of Buenos Aires; Frank Rattray Lillie, Professor of Zoology and Embryology, University of Chicago; Thomas Hunt Morgan, Nobel Laureate, Medicine, Professor of Biology, California Institute of Technology, Pasadena; Paul Sabatier, Nobel Laureate, Chemistry, Professor of Chemistry, University of Toulouse; Theobald Smith, formerly Director of Rockefeller Institute for Medical Research, Princeton, New Jersey.

British: Henry Edward Armstrong, Ph.D., LL.D., F.R.S., Emeritus Professor of Chemistry, Imperial College of Science and Technology, City and Guilds (Engineering) College,

London; JOHN SCOTT HALDANE, C.H., M.A., M.D., LL.D., F.R.S., Director of the Mining Research Laboratory, and Honorary Professor, University of Birmingham; KARL PEARSON, M.A., LL.B., LL.D., F.R.S., Emeritus Galton Professor of Eugenics, University of London; EDWARD BAGNALL POULTON, M.A., D.Sc., LL.D., F.R.S., lately Hope Professor of Zoology, University of Oxford; Sir GRAFTON ELLIOT SMITH, Kt., M.A., M.D., Litt.D., F.R.S., Professor of Anatomy, University College, London; WILLIAM WHITEHEAD WATTS, Sc.D., LL.D., F.R.S., Emeritus Professor of Geology, Imperial College of Science and Technology, London.

At the request of the Council an Address was delivered by Professor D'ARCY W. THOMPSON, C.B., LL.D., F.R.S., entitled "Fifty Years Ago." *Proc.*, vol. 54, pp. 145–157.

At the conclusion of this Address the President moved a vote of thanks from the Society to Professor D'ARCY W. THOMPSON, and this motion was carried with acclamation.

On the evening of the same date, a Reception was given by the Lord Provost, Magistrates and Council of the City of Edinburgh to the Fellows of the Society in the Galleries of the Royal Scottish Academy (by courtesy of the President and Council).

SEVENTH ORDINARY MEETING.

Monday, June 4, 1934.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

The following gentlemen signed the Roll of Fellows and were inducted by the President: Dr DAVID BAIN, Dr F. FRASER DARLING, Dr R. CRANSTON LOW, Brig.-Gen. MAGNUS MOWAT, Mr W. G. R. MURRAY, Professor A. R. NORMAND, and Dr H. J. PLENDERLEITH.

The following Communications were submitted:—

1. Graphical Classification of Carbonaceous Minerals: the Mineral Oils. By Professor H. BRIGGS, D.Sc. *Proc.*, vol. 54, pp. 115–120.

2. Products of the Natural Development of Coal and Oil. By Professor H. BRIGGS, D.Sc. *Proc.*, vol. 54, pp. 121–134.

3. Notes on the Kidston Collection of Fossil Plant Slides. No. V.—On the Structure of Two Lower Carboniferous Lepidodendroid Stems, one of the *Lepidophloios Wünschianus* type, and the other of the *Lepidodendron fuliginosum* type. No. VI.—On the Structure of Two Lepidodendroid Stems from the Carboniferous Flora of Berwickshire. By MARY G. CALDER, B.Sc., Ph.D. Communicated by Dr S. WILLIAMS. *Trans.*, vol. 58, pp. 113–124.

4. On a New Species of *Psygmophyllum* from the Upper Carboniferous of Scotland. By JESSIE A. R. WILSON, B.Sc., Ph.D. Communicated by Professor J. WALTON, D.Sc. *Proc.*, vol. 54, pp. 188–192.

The following Papers were read by title:—

5. The Photoelectric Thresholds of some Turned Metallic Surfaces. By J. S. HUNTER, B.Sc. Communicated by Professor H. S. ALLEN, F.R.S. *Proc.*, vol. 54, pp. 102–108.

6. Note on the Electron Configurations p^3s, p^4s. By ROBERT SCHLAPP, M.A., Ph.D. *Proc.*, vol. 54, pp. 109–114.

EIGHTH ORDINARY MEETING.

Monday, July 2, 1934.

Emeritus Professor Sir E. A. Sharpey-Schafer, F.R.S., President, in the Chair.

The Minutes of the previous Ordinary Meeting were taken as read, and signed.

Dr R. M. GORRIE and Mr W. P. D. WIGHTMAN signed the Roll, and were admitted to the Society by the President.

Voting for the election of Honorary Fellows then took place. The President nominated Mr GALL INGLIS and Dr C. H. O'DONOGHUE as Scrutineers. No name was deleted from any of the voting papers. The President announced that the following Honorary Fellows were duly elected:—

Foreign: BJÖRN HELLAND-HANSEN, BERNARDO HOUSSAY, FRANK RATTRAY LILLIE, THOMAS HUNT MORGAN, PAUL SABATIER, THEOBALD SMITH.

British: HENRY EDWARD ARMSTRONG, JOHN SCOTT HALDANE, KARL PEARSON, EDWARD BAGNALL POULTON, Sir GRAFTON ELLIOT SMITH, WILLIAM WHITEHEAD WATTS.

The President then presented the KEITH and the NEILL PRIZES for the period 1931–1933.

The KEITH PRIZE was presented to Dr A. CRICHTON MITCHELL for his paper on "The Diurnal Incidence of Disturbance in the Terrestrial Magnetic Field," published in the *Transactions* within the period of the award. In making the presentation, the President said:—

> The award of the KEITH PRIZE to Dr A. CRICHTON MITCHELL for his paper "The Diurnal Incidence of Disturbance in the Terrestrial Magnetic Field" recognises his long study and illumination of problems in terrestrial magnetism. Though technically it makes award possible, it is not the only ground for the award, for many of us have recognised with pleasure his recent publication of his studies on the history of the question in the journal *Terrestrial Magnetism*. Moreover, during his tenure of the position of Superintendent of the Meteorological Office, first at Eskdalemuir and then here in Edinburgh, his interest in this question received practical expression.
>
> It is only doing justice to add that Dr CRICHTON MITCHELL was himself an Edinburgh student, and has been a devoted Fellow of our Society since 1889.

The President presented the NEILL PRIZE to Dr G. W. TYRRELL for his contributions to the Geology and Petrology of Sub-Arctic and Sub-Antarctic Lands. In making the presentation, the President said:—

> Dr TYRRELL, by his contributions to Petrology in general and more particularly to the Petrology of the West of Scotland, has won a secure position in the esteem of his colleagues in research. On the present occasion attention is focussed upon a side of his activities, which is illustrated in two recent papers, published in the *Transactions* and *Proceedings* of this Society. He is taking a prominent part in the investigation of Sub-Arctic and Sub-Antarctic lands. In 1919 and 1920 he joined expeditions led to Spitzbergen by Dr W. S. BRUCE, and in 1924 travelled extensively in Iceland in company with Dr M. A. PEACOCK. The fruits of these expeditions have been in large measure published. But his influence has extended far beyond the field of his personal explorations; he is frequently entrusted with precious collections brought home by others from the solitudes of both North and South. Already he has published on the Petrology of Jan Mayen, Greenland, South Georgia, and other southern lands bordering upon or included within Antarctica. It is recognised that Dr TYRRELL's descriptions combine careful statements of the local facts with regional comparisons that give them wide significance.

The following Communications were submitted:—

1. The Early Stages in the Development of the Ferret. Fertilisation to the Development of the Prochordal Plate. By W. J. HAMILTON, D.Sc., M.B., B.Ch. Communicated by Professor T. H. BRYCE, F.R.S. *Trans.*, vol. 58, pp. 251–278.
2. The Life History and Structure of *Hæmatopota pluvialis* L. (Tabanidæ). By A. E. CAMERON, M.A., D.Sc. *Trans.*, vol. 58, pp. 211–250.
3. A Study of a Tectibranch Gasteropod Mollusc, *Philine aperta* (L). By H. H. BROWN, M.A. Communicated by Professor J. GRAHAM KERR, F.R.S. *Trans.*, vol. 58, pp. 179–210.

The following Papers were read by title:—

4. The Structure and Relationships of Lamellibranchs possessing a Cruciform Muscle. By ALASTAIR GRAHAM, M.A., B.Sc. Communicated by Professor J. H. ASHWORTH, F.R.S. *Proc.*, vol. 54, pp. 158–187.
5. The Feeding Mechanism of the Cumacean Crustacean *Diastylis bradyi*. By RALPH DENNELL, B.Sc. Communicated by Professor H. GRAHAM CANNON, M.A., Sc.D. *Trans.*, vol. 58, pp. 125–142.
6. Some Integrals, with respect to their Degrees, of Associated Legendre Functions. By Professor T. M. MACROBERT, M.A., D.Sc. *Proc.*, vol. 54, pp. 135–144.

PROCEEDINGS OF THE STATUTORY GENERAL MEETING

Ending the 151st Session, 1933–1934.

At the Statutory General Meeting of the Royal Society of Edinburgh, held in the Society's Rooms, 24 George Street, on Monday, October 22, 1934, at 4.30 P.M.

Professor C. G. Darwin, M.A., F.R.S., Vice-President, in the Chair.

The Minutes of the Statutory Meeting held on October 23, 1933, were read, approved and signed.

The Secretary read a letter from the President expressing his regret that, by his doctor's orders, he could not be present that day to demit his office.

The Chairman nominated as Scrutineers Lt.-Colonel J. C. LAMONT and Mr W. J. M. MENZIES.

The Ballot for the Election of Office-Bearers and Council was then taken.

The General Secretary submitted the following report:—

GENERAL SECRETARY'S REPORT, OCTOBER 22, 1934.

During the session four addresses have been given to the Society by request of the Council. On October 23, 1933, in terms of the award of the BRUCE-PRELLER LECTURE FUND, Professor C. H. LANDER addressed the Society on "The Liquefaction of Coal"; on December 4, 1933, Mr JAMES M. STAGG gave an address on "The British Polar Year Expedition to Fort Rae, 1932–33"; on February 5, 1934, Dr R. A. FLEMING gave an address on "The Psychology of Crime and Criminals, with special reference to Measures for Reformation"; on May 7, 1934, the Society commemorated the completion of its 150th year, and Professor D'ARCY W. THOMPSON, C.B., F.R.S., in an address entitled "Fifty Years Ago," referred to many of the notable personalities of that period and the following four decades. This address is published in the *Proceedings* (vol. 54, pp. 145–157). The President's remarks, which preceded the address, are printed in the Proceedings of the Meetings (pp. 232–233).

On the evening of the same day the Lord Provost, Magistrates, and Council of the City of Edinburgh gave a Reception to the Fellows of the Society in the Galleries of the Royal Scottish Academy (by courtesy of the President and Council). After receiving the Fellows and their friends, the Lord Provost in a short speech of welcome recalled that the Society had been housed in the "Royal Institution" for eighty-three years until in 1909 it removed into the present premises. He referred to the long line of eminent men who had presided over the destinies of the Society and to the services to science rendered by the President, Sir EDWARD SHARPEY-SCHAFER. The President thanked the Lord Provost and Corporation.

28 papers were read, as compared with 41 in the previous session. The papers were divided among subjects as follows:—Mathematics, 4; physics, 1; geology, 3; palaobotany, 3; botany, 1; zoology, 8; animal genetics, 1; physiology, 5; anatomy, 2. 14 papers have been published in the *Transactions*, and 14 in the *Proceedings*. 1 paper has been withdrawn by the author, 9 have been declined as unsuitable for publication by the Society, and several are still under the consideration of the Council.

HIS ROYAL HIGHNESS THE DUKE OF YORK, having graciously consented to be nominated, was elected an Honorary Fellow of the Society at the Ordinary Meeting on March 5, 1934.

The Society has lost by death 21 Fellows and 4 Honorary Fellows; 1 Fellow has resigned. 28 Fellows and 6 Foreign and 6 British Honorary Fellows have been elected.

In commemoration of the completion of the 150th year of the Society, 6 Foreign and 6 British Honorary Fellows were elected. To make the election possible, Law I was altered at the Ordinary Meeting on February 5, 1934, to read as follows:—"The number of Honorary Fellows shall not exceed sixty-six, of whom not more than twenty-two may be British subjects, and not more than forty-four subjects of Foreign States." Formerly the numbers, according to statute, were twenty and thirty-six respectively.

Invitations were received, and the Society was represented as follows on the occasions mentioned:—

1. University of Edinburgh. 350th Anniversary, October 28, 1933. The President, Sir E. A. SHARPEY-SCHAFER, represented the Society, and the Honorary Degree of Doctor of Laws was conferred upon him.
2. Royal Asiatic Society of Bengal. 150th Anniversary, Calcutta, January 15, 1934. Dr A. MACMILLAN HERON, Director of the Geological Survey of India.
3. Ninth International Congress of Pure and Applied Chemistry, Madrid, April 5, 1934. Professor GEORGE BARGER.
4. Dinner of the Scottish Anthropological Society. Edinburgh, May 22, 1934. Professor J. H. ASHWORTH, General Secretary.
5. Commemoration of Antonio Pacinotti. Pisa, May 24, 1934. Letter sent.
6. 20th Annual Conference of the National Association for the Prevention of Tuberculosis. London, June 14–16, 1934. Sir ROBERT PHILIP.
7. 90th Anniversary of the Naturhistorische Verein d. Preussischen Rheinlande u. Westfalens zu Bonn. July 1, 1934. Letter sent.
8. Congrés Internationale des Sciences Anthropologiques et Ethnologiques. London, July 30 to August 4, 1934. Professor J. C. BRASH and Professor V. G. CHILDE.
9. Edinburgh Geological Society Centenary Celebrations. September 3, 4, 1934. Professor J. H. ASHWORTH, General Secretary.
10. Deuxième Congrès des Mathematiciens des Pays Slaves. Prague, September 23–28, 1934. Letter sent.
11. University of Catania. 500th Anniversary, October 19–22, 1934. Professor D'ARCY W. THOMPSON presented address.

The undernoted Fellows were appointed to fill vacancies in the Society's representation on the following National Committees, to serve until December 31, 1939:—

Astronomy . . .	Mr T. L. MACDONALD, Glasgow.
Biology . . .	Professor D'ARCY WENTWORTH THOMPSON.
Geodesy and geophysics	Professor R. A. SAMPSON.
Physics . . .	Professor H. S. ALLEN.
Radio-telegraphy . .	Professor C. G. DARWIN.

Dr A. CRICHTON MITCHELL has been re-appointed as the Society's representative on the Governing Body of the Heriot-Watt College for three years as from January 1, 1934.

Professor R. K. HANNAY has been appointed to succeed the late LORD SANDS as the Society's representative on the Council of the National Trust for Scotland.

The KEITH PRIZE for the period 1931–1933 was awarded to Dr A. CRICHTON MITCHELL, and the NEILL PRIZE for the same period to Dr G. W. TYRRELL.

During the session £225 has been expended on the binding of books, and additional steel and wooden shelving costing approximately £100 has been installed.

A number of publications were added to the Library by exchange, gift, and purchase.

The issue of the *Proceedings* has been increased from 1500 to 1520.

During the session the "Instructions to Authors" on the preparation of papers for the *Transactions* and *Proceedings* have been revised, and the new regulations are printed inside the covers of parts of *Proceedings*. The Council urges on the attention of authors the need for brevity in statement, and for economy in tables and illustrations.

The acknowledgment of the Society is due to the Carnegie Trust for the Universities of Scotland for grants to authors towards the cost of tabular matter and illustrations of papers published in the *Transactions* and *Proceedings* amounting to £155, 12s. 7d.; to the Oxford University Exploration Club Expedition for £12 towards the cost of the paper by Drs TYRRELL and SANDFORD in the *Proceedings*; to Bedford College for Women, London, for £10 towards the cost of Miss E. DIX's paper in the *Transactions*; and for a sum of £300 received from the Royal Society of London, from the Government Publication Grant, in aid of the cost of the Society's publications during the session 1933–1934.

TREASURER'S REPORT:—

The TREASURER, in submitting the Accounts of the past year, referred briefly to the changes in the leading items of Receipts and Expenditure.

Professor E. P. STEBBING moved the adoption of the Reports, and the reappointment of Messrs LINDSAY, JAMIESON & HALDANE, C.A., as auditors for the ensuing session. These motions were approved.

The Scrutineers reported that the Ballot Papers were in order, and the CHAIRMAN declared that the following Office-bearers and Council had been duly elected:—

Professor D'ARCY W. THOMPSON, C.B., D.Litt., D.Sc., LL.D., F.R.S., President.	
Principal Sir THOMAS H. HOLLAND, K.C.S.I., K.C.I.E., D.L., Hon. D.Sc., LL.D., F.R.S.	Vice-Presidents.
Professor C. G. DARWIN, M.A., F.R.S.	
Professor R. A. SAMPSON, M.A., D.Sc., LL.D., F.R.S.	
Principal O. CHARNOCK BRADLEY, M.D., D.Sc.	
Professor P. T. HERRING, M.D., F.R.C.P.E.	
The Most Hon. THE MARQUIS OF LINLITHGOW, K.T., G.C.I.E., D.L.	
Professor J. H. ASHWORTH, D.Sc., F.R.S., General Secretary.	
Professor F. A. E. CREW, M.D., D.Sc., Ph.D.	Secretaries to Ordinary Meetings.
Professor JAMES P. KENDALL, M.A., D.Sc., F.R.S.	
JAMES WATT, W.S., LL.D., Treasurer.	
LEONARD DOBBIN, Ph.D., Curator of Library and Museum.	

MEMBERS OF COUNCIL.

Professor E. B. BAILEY, M.C., M.A., F.R.S.
Professor J. C. BRASH, M.C., M.A., M.D.
Professor A. J. CLARK, M.C., B.A., M.D., F.R.S.
Professor A. G. OGILVIE, O.B.E., M.A., B.Sc.
Professor E. M. WEDDERBURN, O.B.E., M.A., D.Sc., LL.B., W.S.
Lt.-Col. A. G. M'KENDRICK, M.B., D.Sc., F.R.C.P.E.
Emeritus Professor JAMES MACKINNON, M.A., Ph.D., LL.D.
Professor WILLIAM PEDDIE, D.Sc.
ALEXANDER C. AITKEN, M.A., D.Sc.
Principal J. C. SMAIL, A.Inst.E.E.
Sir HAROLD J. STILES, K.B.E., M.B., F.R.C.S.E., LL.D.
Professor JOHN WALTON, M.A., D.Sc.

The CHAIRMAN thanked the Scrutineers for their services.

The Public were then admitted.

The CHAIRMAN, in the course of his remarks, said that we were unfortunate in the absence of both the retiring President and the new one. Professor D'ARCY WENTWORTH THOMPSON was absent abroad representing the Society at the 500th Anniversary of the University of Catania, and Sir EDWARD SCHAFER was prevented by his doctor's orders from coming to-day to demit office. *Under these circumstances he gave a short review of the session's activities, and cited* certain names from the List of Fellows who had died during the session.

In speaking of the retiring President and Curator, and of the work of the General Secretary and Treasurer, the CHAIRMAN said:—

"I must speak of the services of our retiring officers, and here I count it an advantage that the Chair should be occupied by a mere Member of Council, for if either the old or the new President had been *in the Chair it would not have been possible for him to tell of the virtues of all of the* officers.

"We are losing the services of Professor D'ARCY THOMPSON as Curator on his transference to a higher sphere of activity, and it is not possible to let the occasion pass without referring to the great improvements he has made in our library during his period of office. This has been largely due to what I may call the energetic good taste which he has shown in seeing what was needed next.

"We must also congratulate ourselves on the performance of our General Secretary. The continued existence of a society like ours depends more than anything else on the efficiency of its secretary, who does all the work, takes all the blame when things go wrong, but is often not publicly given the credit when things go right. I can assure you that the present prosperity of our Society is mostly due to our General Secretary, and to the assistance he receives from Mr STEWART and the rest of the staff. As to the Treasurer, I shall leave his report to speak for him, but I cannot forbear from pointing out that our grant in aid of publications has been increased by the Royal Society of London to £300. I do not know how much of the increase is due to the persuasive tongue of our Treasurer and the charm of our Secretary but it may surely be taken as an index that our publications are held in good esteem. In this connection I may digress to remind you how deeply our Society is indebted to the Carnegie Trust for the Universities of Scotland. Its generous grants make it possible for us to publish in our journals many important tables, and especially illustrations for papers which otherwise we should have to refuse on the grounds of expense.

"And last I come to our retiring President. It is not possible for one who has chiefly followed other branches of science to give a reasoned account of his work, but it takes no expert to say that he is the doyen of all our physiologists. He is one of the very few men of science who have had the distinction of starting a great new field of knowledge—I refer to the study of the endocrine organs—and have survived to see, years later, their subject advanced to such a state that the mystery has been emptied out of it, so that it takes its place as one of the ordered branches of science. We may rejoice that it has been possible for us to bring a culmination to his life's work by honouring ourselves in having him for our President. Throughout his period of office he has shown a vigour in conducting our business that would be expected in a man of sixty rather than eighty years. It is a matter of great regret that he was not allowed to come here to-day, and in concluding I would like to propose a motion—That the following message be sent to the retiring President:—

"'On the occasion of your retiring from the Presidency, the Society desires to record its gratitude to you for your services during your term of office, and expresses the hope that your health will be soon restored.'"

This motion was carried unanimously.

THE KEITH, MAKDOUGALL-BRISBANE, NEILL, GUNNING VICTORIA JUBILEE, JAMES SCOTT, BRUCE, AND DAVID ANDERSON-BERRY PRIZES, AND THE BRUCE-PRELLER LECTURE FUND.

The above Prizes will be awarded by the Council in the following manner:—

I. KEITH PRIZE.

The KEITH PRIZE, consisting of a Gold Medal and about £30 in Money, will be awarded in the Session 1935–1936 for the "best communication on a scientific subject, communicated,* in the first instance, to the Royal Society of Edinburgh during the Sessions 1933–1934 and 1934–1935." Preference will be given to a Paper containing a discovery. (See also Council's resolutions at the end of these regulations.)

II. MAKDOUGALL-BRISBANE PRIZE.

(*Amended June* 7, 1926.)

This Prize is to be awarded biennially by the Council of the Royal Society of Edinburgh to such person, for such purposes, for such objects, and in such manner as shall appear to them the most conducive to the promotion of the interests of science; with the *proviso* that the Council shall not be compelled to award the Prize unless there shall be some individual engaged in scientific pursuit, or some Paper written on a scientific subject, or some discovery in science made during the biennial period, of sufficient merit or importance in the opinion of the Council to be entitled to the Prize.

1. The Prize, consisting of a Gold Medal and a sum of Money, will be awarded before the close of the Session 1936–1937, for an Essay, Paper, or other work having reference to any branch of scientific inquiry, either material or mental.
2. It is open to all men of science.
3. The specific subjects taken into consideration in the current award are governed by the resolutions of the Council as stated at the end of these regulations.
4. For the current period the Committee is representative of Group A.
5. The Committee will consider Papers presented to the Society within the Sessions 1934–1935 and 1935–1936, and will make a recommendation.

It is empowered to recommend either:—

(*a*) An award to the Author of an Essay or Paper considered as above, or
(*b*) That no award be made on the ground that, within its group, no Paper of sufficient merit has been presented, or

* For the purposes of this award the word "communicated" shall be understood to mean the date on which the manuscript of a Paper is received in its final form for printing, as recorded by the General Secretary or other responsible official.

(*c*) That the Prize be awarded to some distinguished man of learning, who may not have presented a Paper to the Society within the period considered, but who is willing to deliver an address.

III. NEILL PRIZE.

The Council of the Royal Society of Edinburgh having received the bequest of the late Dr PATRICK NEILL of the sum of £500, for the purpose of "the interest thereof being applied in furnishing a Medal or other reward every second or third year to any distinguished Scottish Naturalist, according as such Medal or reward shall be voted by the Council of the said Society," hereby intimate:—

1. The NEILL PRIZE, consisting of a Gold Medal, will be awarded during the Session 1935–1936.

2. The Prize will be given for a Paper of distinguished merit, on a subject of Natural History, by a Scottish Naturalist, which shall have been presented * to the Society during the two years preceding the fourth Monday in October 1935,—or failing presentation of a Paper sufficiently meritorious, it will be awarded for a work or publication by some distinguished Scottish Naturalist, on some branch of Natural History, bearing date within five years of the time of award. (See also Council's resolutions at the end of these regulations.)

IV. GUNNING VICTORIA JUBILEE PRIZE.

This Prize, founded in the year 1887 by Dr R. H. GUNNING, is to be awarded quadrennially by the Council of the Royal Society of Edinburgh, in recognition of original work in Physics, Chemistry, or Pure or Applied Mathematics.

Evidence of such work may be afforded either by a Paper presented * to the Society, or by a Paper on one of the above subjects, or some discovery in them elsewhere communicated or made, which the Council may consider to be deserving of the Prize.

The Prize consists of a sum of money, and is open to men of science resident in or connected with Scotland. The first award was made in the year 1887. The next award will be made in Session 1936–1937.

In accordance with the wish of the Donor, the Council of the Society may on fit occasions award the Prize for work of a definite kind to be undertaken during the three succeeding years by a scientific man of recognised ability.

V. JAMES SCOTT PRIZE.

This Prize, founded in the year 1918 by the Trustees of the JAMES SCOTT Bequest, is to be awarded triennially, or at such intervals as the Council of the Royal Society of Edinburgh may decide, "for a lecture or essay on the fundamental concepts of Natural Philosophy."

* For the purposes of this award the word "presented" shall be understood to mean the date on which the manuscript of a Paper is received in its final form for printing, as recorded by the General Secretary or other responsible official.

VI. BRUCE PRIZE.

The Society is trustee of a fund, instituted in 1923, to commemorate the work of Dr W. S. BRUCE as an explorer and scientific investigator in polar regions.

The Committee of Award is appointed jointly by the Royal Society of Edinburgh, the Royal Physical Society, and the Royal Scottish Geographical Society.

The Prize consists of a Bronze Medal and sum of Money. It is open to workers of all nationalities, with a preference, *ceteris paribus*, for those of Scottish birth or origin, and is to be awarded biennially for some notable contribution to Natural Sciences, such as Zoology, Botany, Geology, Meteorology, Oceanography, and Geography; the contribution to be in the nature of new knowledge, the outcome of a personal visit to polar regions on the part of the recipient. The recipient shall preferably be at the outset of his career as an investigator.

The next award will be made in 1936. Papers for the consideration of the Committee should be in the hands of the General Secretary of the Royal Society, 22 George Street, Edinburgh 2, not later than March 31 of that year.

VII. BRUCE-PRELLER LECTURE FUND.

The Council of the Royal Society of Edinburgh having received in 1929 the bequest of the late Dr CHARLES DU RICHE PRELLER of the sum of £500, decided that the income thereof be applied by the Council biennially as an honorarium for a special BRUCE-PRELLER Lecture or Address by an outstanding man of science, its subject to be Geology or Electrical or Physical Science, or in the discretion of the Council some other branch of science. The next award will be made in Session 1936–1937.

VIII. DAVID ANDERSON-BERRY FUND.

The Council of the Royal Society of Edinburgh having received in the year 1930, free of duty, the capital sum of one thousand pounds (£1000), to be used in terms of the will of the late Dr DAVID ANDERSON-BERRY, dated 23rd April 1926, decided that the income thereof be applied triennially, "in the first place in the presentation of a gold medal, and in the second place in the payment of a sum of money to the winner for the year of such gold medal, the winner being the person who, in the opinion of the Society, shall be the producer for the year of the best essay on the nature of X-rays and their therapeutical effect on human diseases."

The first award will be made in July 1935.

RESOLUTIONS OF COUNCIL IN REGARD TO THE MODE OF AWARDING PRIZES.

(*See Minutes of Meeting of January* 18, 1915.)

I. With regard to the Keith and Makdougall-Brisbane Prizes, which are open to all Sciences, the mode of award will be as follows:—

1. Papers or essays to be considered shall be arranged in two groups, A and B,—Group A to include Astronomy, Chemistry, Mathematics, Metallurgy, Meteorology, and Physics; Group B to include Anatomy, Anthropology, Botany, Geology, Pathology, Physiology, and Zoology.
2. These two prizes shall be awarded to each group in alternate biennial periods, provided Papers worthy of recommendation have been communicated to the Society.
3. Prior to the adjudication the Council shall appoint, in the first instance, a Committee composed of representatives of the group of Sciences which did not receive the award in the immediately preceding period. The Committee shall consider the Papers which come within their group of Sciences, and report in due course to the Council.
4. In the event of the aforesaid Committee reporting that within their group of subjects there is, in their opinion, no Paper worthy of being recommended for the award, the Council, on accepting this report, shall appoint a Committee representative of the alternate group to consider Papers coming within their group and to report accordingly.
5. Papers to be considered by the Committees shall fall within the period dating from the last award in groups A and B respectively.

II. With regard to the Neill Prize, the term "Naturalist" shall be understood to include any student in the Sciences composing group B, namely, Anatomy, Anthropology, Botany, Geology, Pathology, Physiology, Zoology.

AWARDS OF THE KEITH, MAKDOUGALL-BRISBANE, NEILL, GUNNING, JAMES SCOTT, BRUCE, AND DAVID ANDERSON-BERRY PRIZES, AND THE BRUCE-PRELLER LECTURE FUND.

I. KEITH PRIZE.

1ST BIENNIAL PERIOD, 1827–29.—Dr BREWSTER, for his papers "on his Discovery of Two New Immiscible Fluids in the Cavities of certain Minerals," published in the Transactions of the Society.

2ND BIENNIAL PERIOD, 1829–31.—Dr BREWSTER, for his paper "on a New Analysis of Solar Light," published in the Transactions of the Society.

3RD BIENNIAL PERIOD, 1831–33.—THOMAS GRAHAM, Esq., for his paper "on the Law of the Diffusion of Gases," published in the Transactions of the Society.

4TH BIENNIAL PERIOD, 1833–35.—Professor J. D. FORBES, for his paper "on the Refraction and Polarization of Heat," published in the Transactions of the Society.

5TH BIENNIAL PERIOD, 1835–37.—JOHN SCOTT RUSSELL, Esq., for his researches "on Hydrodynamics," published in the Transactions of the Society.

6TH BIENNIAL PERIOD, 1837–39.—Mr JOHN SHAW, for his experiments "on the Development and Growth of the Salmon," published in the Transactions of the Society.

7TH BIENNIAL PERIOD, 1839–41.—Not awarded.

8TH BIENNIAL PERIOD, 1841–43.—Professor JAMES DAVID FORBES, for his papers "on Glaciers," published in the Proceedings of the Society.

9TH BIENNIAL PERIOD, 1843–45.—Not awarded.

10TH BIENNIAL PERIOD, 1845–47.—General Sir THOMAS BRISBANE, Bart., for the Makerstoun Observations on Magnetic Phenomena, made at his expense, and published in the Transactions of the Society.

11TH BIENNIAL PERIOD, 1847–49.—Not awarded.

12TH BIENNIAL PERIOD, 1849–51.—Professor KELLAND, for his papers "on General Differentiation, including his more recent Communication on a process of the Differential Calculus, and its application to the solution of certain Differential Equations," published in the Transactions of the Society.

13TH BIENNIAL PERIOD, 1851–53.—W. J. MACQUORN RANKINE, Esq., for his series of papers "on the Mechanical Action of Heat," published in the Transactions of the Society.

14TH BIENNIAL PERIOD, 1853–55.—Dr THOMAS ANDERSON, for his papers "on the Crystalline Constituents of Opium, and on the Products of the Destructive Distillation of Animal Substances," published in the Transactions of the Society.

15TH BIENNIAL PERIOD, 1855–57.—Professor BOOLE, for his Memoir "on the Application of the Theory of Probabilities to Questions of the Combination of Testimonies and Judgments," published in the Transactions of the Society.

16TH BIENNIAL PERIOD, 1857–59.—Not awarded.

17TH BIENNIAL PERIOD, 1859–61.—JOHN ALLAN BROUN, Esq., F.R.S., Director of the Trevandrum Observatory, for his papers "on the Horizontal Force of the Earth's Magnetism, on the Correction of the Bifilar Magnetometer, and on Terrestrial Magnetism generally," published in the Transactions of the Society.

18TH BIENNIAL PERIOD, 1861–63.—Professor WILLIAM THOMSON, of the University of Glasgow, for his Communication "on some Kinematical and Dynamical Theorems."

19TH BIENNIAL PERIOD, 1863–65.—Principal FORBES, St Andrews, for his "Experimental Inquiry into the Laws of Conduction of Heat in Iron Bars," published in the Transactions of the Society.

20TH BIENNIAL PERIOD, 1865–67.—Professor C. PIAZZI SMYTH, for his paper "on Recent Measures at the Great Pyramid," published in the Transactions of the Society.

21ST BIENNIAL PERIOD, 1867–69.—Professor P. G. TAIT, for his paper "on the Rotation of a Rigid Body about a Fixed Point," published in the Transactions of the Society.

22ND BIENNIAL PERIOD, 1869–71.—Professor CLERK MAXWELL, for his paper "on Figures, Frames, and Diagrams of Forces," published in the Transactions of the Society.

23RD BIENNIAL PERIOD, 1871–73.—Professor P. G. TAIT, for his paper entitled "First Approximation to a Thermo-electric Diagram," published in the Transactions of the Society.

24TH BIENNIAL PERIOD, 1873–75.—Professor CRUM BROWN, for his Researches "on the Sense of Rotation, and on the Anatomical Relations of the Semicircular Canals of the Internal Ear."

25TH BIENNIAL PERIOD, 1875–77.—Professor M. FORSTER HEDDLE, for his papers "on the Rhombohedral Carbonates," and "on the Felspars of Scotland," published in the Transactions of the Society.

26TH BIENNIAL PERIOD, 1877–79.—Professor H. C. FLEEMING JENKIN, for his paper "on the Application of Graphic Methods to the Determination of the Efficiency of Machinery," published in the Transactions of the Society; Part II having appeared in the volume for 1877–78.

27TH BIENNIAL PERIOD, 1879–81.—Professor GEORGE CHRYSTAL, for his paper "on the Differential Telephone," published in the Transactions of the Society.

28TH BIENNIAL PERIOD, 1881–83.—THOMAS MUIR, Esq., LL.D., for his "Researches into the Theory of Determinants and Continued Fractions," published in the Proceedings of the Society.

29TH BIENNIAL PERIOD, 1883–85.—JOHN AITKEN, Esq., for his paper "on the Formation of Small Clear Spaces in Dusty Air," and for previous papers on Atmospheric Phenomena, published in the Transactions of the Society.

30TH BIENNIAL PERIOD, 1885–87.—JOHN YOUNG BUCHANAN, Esq., for a series of communications, extending over several years, on subjects connected with Ocean Circulation, Compressibility of Glass, etc.; two of which, viz., "On Ice and Brines," and "On the Distribution of Temperature in the Antarctic Ocean," have been published in the Proceedings of the Society.

31ST BIENNIAL PERIOD, 1887–89.—Professor E. A. LETTS, for his papers on the Organic Compounds of Phosphorus, published in the Transactions of the Society.

32ND BIENNIAL PERIOD, 1889–91.—R. T. OMOND, Esq., for his contributions to Meteorological Science, many of which are contained in vol. xxxiv of the Society's Transactions.

33RD BIENNIAL PERIOD, 1891–93.—Professor THOMAS R. FRASER, F.R.S., for his papers on *Strophanthus hispidus*, Strophanthin, and Strophanthidin, read to the Society in February and June 1889 and in December 1891, and printed in vols. xxxv, xxxvi, and xxxvii of the Society's Transactions.

34TH BIENNIAL PERIOD, 1893–95.—Dr CARGILL G. KNOTT, for his papers on the Strains produced by Magnetism in Iron and in Nickel, which have appeared in the Transactions and Proceedings of the Society.

35TH BIENNIAL PERIOD, 1895–97.—Dr THOMAS MUIR, for his continued communications on Determinants and Allied Questions.

36TH BIENNIAL PERIOD, 1897–99.—Dr JAMES BURGESS, for his paper "on the Definite Integral $\frac{2}{\sqrt{\pi}}\int_0^t e^{-t^2}dt$, with extended Tables of Values," printed in vol. xxxix of the Transactions of the Society.

37TH BIENNIAL PERIOD, 1899–1901.—Dr HUGH MARSHALL, for his discovery of the Persulphates, and for his Communications on the Properties and Reactions of these Salts, published in the Proceedings of the Society.

38TH BIENNIAL PERIOD, 1901–03.—Sir WILLIAM TURNER, K.C.B., LL.D., F.R.S., etc., for his memoirs entitled "A Contribution to the Craniology of the People of Scotland," published in the Transactions of the Society, and for his "Contributions to the Craniology of the People of the Empire of India," Parts I, II, likewise published in the Transactions of the Society.

39TH BIENNIAL PERIOD, 1903–05.—THOMAS H. BRYCE, M.A., M.D., for his two papers on "The Histology of the Blood of the Larva of *Lepidosiren paradoxa*," published in the Transactions of the Society within the period.

40TH BIENNIAL PERIOD, 1905–07.—ALEXANDER BRUCE, M.A., M.D., F.R.C.P.E., for his paper entitled "Distribution of the Cells in the Intermedio-Lateral Tract of the Spinal Cord," published in the Transactions of the Society within the period.

41ST BIENNIAL PERIOD, 1907–09.—WHEELTON HIND, M.D., B.S., F.R.C.S., F.G.S., for a paper published in the Transactions of the Society, "On the Lamellibranch and Gasteropod Fauna found in the Millstone Grit of Scotland."

42ND BIENNIAL PERIOD, 1909–11.—Professor ALEXANDER SMITH, B.Sc., Ph.D., of New York, for his researches upon "Sulphur" and upon "Vapour Pressure," appearing in the Proceedings of the Society.

43RD BIENNIAL PERIOD, 1911–13.—JAMES RUSSELL, Esq., for his series of investigations relating to magnetic phenomena in metals and the molecular theory of magnetism, the results of which have been published in the Proceedings and Transactions of the Society, the last paper having been issued within the period.

44TH BIENNIAL PERIOD, 1913–15.—JAMES HARTLEY ASHWORTH, D.Sc., for his papers on "Larvæ of Lingula and Pelagodiscus," and on "Sclerocheilus," published in the Transactions of the Society, and for other papers on the Morphology and Histology of Polychæta.

45TH BIENNIAL PERIOD, 1915–17.—ROBERT C. MOSSMAN, Esq., for his work on the Meteorology of the Antarctic Regions, which originated with the important series of observations made by him during the voyage of the "Scotia" (1902–1904), and includes his paper "On a Sea-Saw of Barometric Pressure, Temperature, and Wind Velocity between the Weddell Sea and the Ross Sea," published in the Proceedings of the Society.

46TH BIENNIAL PERIOD, 1917–19.—JOHN STEPHENSON, Lt.-Col., I.M.S., for his series of papers on the Oligochæta and other Annelida, several of which have been published in the Transactions of the Society.

47TH BIENNIAL PERIOD, 1919–21.—RALPH ALLEN SAMPSON, F.R.S., for his Astronomical Researches, including the papers "Studies in Clocks and Time-keeping: No. 1, Theory of the Maintenance of Motion; No. 2, Tables of the Circular Equation," published in the Proceedings of the Society within the period of the award.

48TH BIENNIAL PERIOD, 1921–23.—JOHN WALTER GREGORY, F.R.S., for his papers published in the Transactions of the Society, and in recognition of his numerous contributions to Geology, extending over a period of thirty-six years.

49TH BIENNIAL PERIOD, 1923–25.—HERBERT WESTREN TURNBULL, M.A., for the papers on "Hyper-Algebra," "Invariant Theory," and "Algebraic Geometry," three of which have been published in the Proceedings within the period of award.

50TH BIENNIAL PERIOD, 1925–27.—THOMAS JOHN JEHU, M.A., M.D., F.G.S., and ROBERT MELDRUM CRAIG, M.A., B.Sc., F.G.S., for the joint series of papers which have recently appeared in the Transactions of the Society on the "Geology of the Outer Hebrides."

51ST BIENNIAL PERIOD, 1927–29.—CHRISTINA C. MILLER, B.Sc., Ph.D., for her papers on the "Slow Oxidation of Phosphorus Trioxide," published in the Proceedings within the period of the award, and in consideration of subsequent developments on "Slow Oxidation of Phosphorus," published elsewhere.

52ND BIENNIAL PERIOD, 1929–31.—ALAN WILLIAM GREENWOOD, M.Sc., Ph.D., for his papers on the "Biology of the Fowl," several of which have appeared in the Proceedings within the period of award.

53RD BIENNIAL PERIOD, 1931–33.—A. CRICHTON MITCHELL, D.Sc., for his paper "On the Diurnal Incidence of Disturbance in the Terrestrial Magnetic Field," published in the Transactions within the period of award.

II. MAKDOUGALL-BRISBANE PRIZE.

1ST BIENNIAL PERIOD, 1859.—Sir RODERICK IMPEY MURCHISON, on account of his Contributions to the Geology of Scotland.

2ND BIENNIAL PERIOD, 1860–62.—WILLIAM SELLER, M.D., F.R.C.P.E., for his "Memoir of the Life and Writings of Dr Robert Whytt," published in the Transactions of the Society.

3RD BIENNIAL PERIOD, 1862–64.—JOHN DENIS MACDONALD, Esq., R.N., F.R.S., Surgeon of H.M.S. "Icarus," for his paper "on the Representative Relationships of the Fixed and Free Tunicata, regarded as Two Sub-classes of equivalent value; with some General Remarks on their Morphology," published in the Transactions of the Society.

4TH BIENNIAL PERIOD, 1864–66.—Not awarded.

5TH BIENNIAL PERIOD, 1866–68.—Dr ALEXANDER CRUM BROWN and Dr THOMAS RICHARD FRASER, for their conjoint paper "on the Connection between Chemical Constitution and Physiological Action," published in the Transactions of the Society.

6TH BIENNIAL PERIOD, 1868–70.—Not awarded.

7TH BIENNIAL PERIOD, 1870–72.—GEORGE JAMES ALLMAN, M.D., F.R.S., Emeritus Professor of Natural History, for his paper "on the Homological Relations of the Cœlenterata," published in the Transactions, which forms a leading chapter of his Monograph of Gymnoblastic or Tubularian Hydroids—since published.

8TH BIENNIAL PERIOD, 1872–74.—Professor LISTER, for his paper "on the Germ Theory of Putrefaction and the Fermentive Changes," communicated to the Society, 7th April 1873.

9TH BIENNIAL PERIOD, 1874–76.—ALEXANDER BUCHAN, A.M., for his paper "on the Diurnal Oscillation of the Barometer," published in the Transactions of the Society.

10TH BIENNIAL PERIOD, 1876–78.—Professor ARCHIBALD GEIKIE, for his paper "on the Old Red Sandstone of Western Europe," published in the Transactions of the Society.

11TH BIENNIAL PERIOD, 1878–80.—Professor PIAZZI SMYTH, Astronomer-Royal for Scotland, for his paper "on the Solar Spectrum in 1877–78, with some Practical Idea of its probable Temperature of Origination," published in the Transactions of the Society.

12TH BIENNIAL PERIOD, 1880–82.—Professor JAMES GEIKIE, for his "Contributions to the Geology of the North-West of Europe," including his paper "on the Geology of the Faroes," published in the Transactions of the Society.

13TH BIENNIAL PERIOD, 1882–84.—EDWARD SANG, Esq., LL.D., for his paper "on the Need of Decimal Subdivisions in Astronomy and Navigation, and on Tables requisite therefor," and generally for his Recalculations of Logarithms both of Numbers and Trigonometrical Ratios—the former communication being published in the Proceedings of the Society.

14TH BIENNIAL PERIOD, 1884–86.—JOHN MURRAY, Esq., LL.D., for his papers "On the Drainage Areas of Continents and Ocean Deposits," "The Rainfall of the Globe, and Discharge of Rivers," "The Height of the Land and Depth of the Ocean," and "The Distribution of Temperature in the Scottish Lochs as affected by the Wind."

15TH BIENNIAL PERIOD, 1886–88.—ARCHIBALD GEIKIE, Esq., LL.D., for numerous Communications, especially that entitled "History of Volcanic Action during the Tertiary Period in the British Isles," published in the Transactions of the Society.

16TH BIENNIAL PERIOD, 1888–90.—Dr LUDWIG BECKER, for his paper on "The Solar Spectrum at Medium and Low Altitudes," printed in vol. xxxvi, Part I, of the Society's Transactions.

17TH BIENNIAL PERIOD, 1890–92.—HUGH ROBERT MILL, Esq., D.Sc., for his papers on "The Physical Conditions of the Clyde Sea Area," Part I being already published in vol. xxxvi of the Society's Transactions.

18TH BIENNIAL PERIOD, 1892–94.—Professor JAMES WALKER, D.Sc., Ph.D., for his work on Physical Chemistry, part of which has been published in the Proceedings of the Society, vol. xx, pp. 255–263. In making this award, the Council took into consideration the work done by Professor Walker along with Professor Crum Brown on the Electrolytic Synthesis of Dibasic Acids, published in the Transactions of the Society.

19TH BIENNIAL PERIOD, 1894–96.—Professor JOHN G. M'KENDRICK, for numerous Physiological papers, especially in connection with Sound, many of which have appeared in the Society's publications.

20TH BIENNIAL PERIOD, 1896–98.—Dr WILLIAM PEDDIE, for his papers on the Torsional Rigidity of Wires.

21ST BIENNIAL PERIOD, 1898–1900.—Dr RAMSAY H. TRAQUAIR, for his paper entitled "Report on Fossil Fishes collected by the Geological Survey in the Upper Silurian Rocks of Scotland," printed in vol. xxxix of the Transactions of the Society.

22ND BIENNIAL PERIOD, 1900–02.—Dr ARTHUR T. MASTERMAN, for his paper entitled "The Early Development of *Cribrella oculata* (Forbes), with remarks on Echinoderm Development," printed in vol. xl of the Transactions of the Society.

23RD BIENNIAL PERIOD, 1902–04.—JOHN DOUGALL, M.A., for his paper on "An Analytical Theory of the Equilibrium of an Isotropic Elastic Plate," published in vol. xli of the Transactions of the Society.

24TH BIENNIAL PERIOD, 1904–06.—JACOB E. HALM, Ph.D., for his two papers entitled "Spectroscopic Observations of the Rotation of the Sun," and "Some Further Results obtained with the Spectroheliometer," and for other astronomical and mathematical papers published in the Transactions and Proceedings of the Society within the period.

25TH BIENNIAL PERIOD, 1906–08.—D. T. GWYNNE-VAUGHAN, M.A., F.L.S., for his papers, 1st, "On the Fossil Osmundaceæ," and 2nd, "On the Origin of the Adaxially-curved Leaf-trace in the Filicales," communicated by him conjointly with Dr R. Kidston.

26TH BIENNIAL PERIOD, 1908–10.—ERNEST MACLAGAN WEDDERBURN, M.A., LL.B., for his series of papers bearing upon "The Temperature Distribution in Fresh-water Lochs," and especially upon "The Temperature Seiche."

27TH BIENNIAL PERIOD, 1910–12.—JOHN BROWNLEE, M.A., M.D., D.Sc., for his contributions to the Theory of Mendelian Distributions and cognate subjects, published in the Proceedings of the Society within and prior to the prescribed period.

28TH BIENNIAL PERIOD, 1912–14.—Professor C. R. MARSHALL, M.A., M.D., for his studies "On the Pharmacological Action of Tetra-alkyl-ammonium Compounds."

29TH BIENNIAL PERIOD, 1914–16.—ROBERT ALEXANDER HOUSTOUN, Ph.D., D.Sc., for his series of papers on "The Absorption of Light by Inorganic Salts," published in the Proceedings of the Society.

30TH BIENNIAL PERIOD, 1916–18.—Professor A. ANSTRUTHER LAWSON, for his Memoirs on "The Prothalli of *Tmesipteris Tannensis* and of *Psilotum*," published in the Transactions of the Society, together with previous papers on Cytology and on The Gametophytes of various Gymnosperms.

31ST BIENNIAL PERIOD, 1918–20.—Professor J. H. MACLAGAN WEDDERBURN of Princeton University, for his Memoirs in Universal Algebra, etc., published in the Transactions and Proceedings of the Society, and elsewhere.

32ND BIENNIAL PERIOD, 1920–22.—Professor W. T. GORDON, M.A., D.Sc., for his paper on "Cambrian Organic Remains from a Dredging in the Weddell Sea," published in the Transactions of the Society within the period, and for his investigations on the Fossil Flora of the Pettycur Limestone, previously published in the Transactions.

33RD BIENNIAL PERIOD, 1922–24.—Professor H. STANLEY ALLEN, D.Sc., for his papers on the "Quantum and Atomic Theory," published in the Society's Proceedings within the period.

34TH BIENNIAL PERIOD, 1924–26.—CHARLES MORLEY WENYON, C.M.G., C.B.E., F.R.S., for his distinguished work in Protozoology extending over a period of twenty-one years.

35TH BIENNIAL PERIOD, 1926–28.—W. O. KERMACK, M.A., D.Sc., for his contributions to Chemistry, published in the Society's Proceedings and elsewhere.

36TH BIENNIAL PERIOD, 1928–30.—NELLIE B. EALES, D.Sc., for her papers in the Society's Transactions on "The Anatomy of a Fœtal African Elephant."

37TH BIENNIAL PERIOD, 1930–32.—A. C. AITKEN, M.A., D.Sc., for various contributions to Mathematics, published in the Society's Proceedings and elsewhere.

III. THE NEILL PRIZE.

1ST TRIENNIAL PERIOD, 1856–59.—Dr W. LAUDER LINDSAY, for his paper "on the Spermogones and Pycnides of Filamentous, Fruticulose, and Foliaceous Lichens," published in the Transactions of the Society.

2ND TRIENNIAL PERIOD, 1859–62.—ROBERT KAYE GREVILLE, LL.D., for his contributions to Scottish Natural History, more especially in the department of Cryptogamic Botany, including his recent papers on Diatomaceæ.

3RD TRIENNIAL PERIOD, 1862–65.—ANDREW CROMBIE RAMSAY, F.R.S., Professor of Geology in the Government School of Mines, and Local Director of the Geological Survey of Great Britain, for his various works and memoirs published during the last five years, in which he has applied the large experience acquired by him in the Direction of the arduous work of the Geological Survey of Great Britain to the elucidation of important questions bearing on Geological Science.

4TH TRIENNIAL PERIOD, 1865–68.—Dr WILLIAM CARMICHAEL M'INTOSH, for his paper "on the Structure of the British Nemerteans, and on some New British Annelids," published in the Transactions of the Society.

5TH TRIENNIAL PERIOD, 1868–71.—Professor WILLIAM TURNER, for his papers "on the Great Finner Whale; and on the Gravid Uterus, and the Arrangement of the Fœtal Membranes in the Cetacea," published in the Transactions of the Society.

6TH TRIENNIAL PERIOD, 1871–74.—CHARLES WILLIAM PEACH, Esq., for his Contributions to Scottish Zoology and Geology, and for his recent contributions to Fossil Botany.

7TH TRIENNIAL PERIOD, 1874–77.—Dr RAMSAY H. TRAQUAIR, for his paper "on the Structure and Affinities of *Tristichopterus alatus* (Egerton)," published in the Transactions of the Society, and also for his contributions to the Knowledge of the Structure of Recent and Fossil Fishes.

8TH TRIENNIAL PERIOD, 1877–80.—JOHN MURRAY, Esq., for his paper "on the Structure and Origin of Coral Reefs and Islands," published (in abstract) in the Proceedings of the Society.

9TH TRIENNIAL PERIOD, 1880–83.—Professor W. A. HERDMAN, for his papers "on the Tunicata," published in the Proceedings and Transactions of the Society.

10TH TRIENNIAL PERIOD, 1883–86.—B. N. PEACH, Esq., for his Contributions to the Geology and Palæontology of Scotland, published in the Transactions of the Society.

11TH TRIENNIAL PERIOD, 1886–89.—ROBERT KIDSTON, Esq., for his Researches in Fossil Botany, published in the Transactions of the Society.

12TH TRIENNIAL PERIOD, 1889–92.—JOHN HORNE, Esq., F.G.S., for his Investigations into the Geological Structure and Petrology of the North-West Highlands.

13TH TRIENNIAL PERIOD, 1892–95.—ROBERT IRVINE, Esq., for his papers on the Action of Organisms in the Secretion of Carbonate of Lime and Silica, and on the solution of these substances in Organic Juices. These are printed in the Society's Transactions and Proceedings.

14TH TRIENNIAL PERIOD, 1895–98.—Professor J. COSSAR EWART, for his recent Investigations connected with Telegony.

15TH TRIENNIAL PERIOD, 1898–1901.—Dr JOHN S. FLETT, for his papers entitled "The Old Red Sandstone of the Orkneys" and "The Trap Dykes of the Orkneys," printed in vol. xxxix of the Transactions of the Society.

16TH TRIENNIAL PERIOD, 1901–04.—Professor J. GRAHAM KERR, M.A., for his Researches on *Lepidosiren paradoxa*, published in the Philosophical Transactions of the Royal Society, London.

17TH TRIENNIAL PERIOD, 1904–07.—FRANK J. COLE, B.Sc., for his paper entitled "A Monograph on the General Morphology of the Myxinoid Fishes, based on a Study of Myxine," published in the Transactions of the Society, regard being also paid to Mr Cole's other valuable contributions to the Anatomy and Morphology of Fishes.

1ST BIENNIAL PERIOD, 1907–09.—FRANCIS J. LEWIS, M.Sc., F.L.S., for his papers in the Society's Transactions "On the Plant Remains of the Scottish Peat Mosses."

2ND BIENNIAL PERIOD, 1909–11.—JAMES MURRAY, Esq., for his paper on "Scottish Rotifers collected by the Lake Survey (Supplement)," and other papers on the "Rotifera" and "Tardigrada," which appeared in the Transactions of the Society—(this Prize was awarded after consideration of the papers received within the five years prior to the time of award: see Neill Prize Regulations).

3RD BIENNIAL PERIOD, 1911–13.—W. S. BRUCE, LL.D., in recognition of the scientific results of his Arctic and Antarctic explorations.

4TH BIENNIAL PERIOD, 1913–15.—ROBERT CAMPBELL, D.Sc., for his paper on "The Upper Cambrian Rocks at Craigeven Bay, Stonehaven," and "Downtonian and Old Red Sandstone Rocks of Kincardineshire," published in the Transactions of the Society.

5TH BIENNIAL PERIOD, 1915–17.—W. H. LANG, F.R.S., M.B., D.Sc., for his paper in conjunction with Dr R. KIDSTON, F.R.S., on *Rhynia Gwynne-Vaughani*, Kidston and Lang, published in the Transactions of the Society, and for his previous investigations on Pteridophytes and Cycads.

6TH BIENNIAL PERIOD, 1917–19.—JOHN TAIT, D.Sc., M.D., for his work on Crustacea, published in the Proceedings of the Society, and for his papers on the blood of Crustacea.

7TH BIENNIAL PERIOD, 1919–21.—Sir EDWARD A. SHARPEY-SCHAFER, F.R.S., for his recent contributions to our knowledge of Physiology, and in recognition of his published work extending over a period of fifty years.

8TH BIENNIAL PERIOD, 1921–23.—JOHN M'LEAN THOMPSON, M.A., D.Sc., University of Liverpool, for his series of Memoirs on Staminal Zygomorphy, and on the Anatomy of the Filicales.

9TH BIENNIAL PERIOD, 1923–25.—FREDERICK ORPEN BOWER, F.R.S., for his recent contributions to Botanical knowledge and in recognition of his published work extending over a period of forty-five years.

10TH BIENNIAL PERIOD, 1925–27.—ARTHUR ROBINSON, M.D., M.R.C.S., for his contributions to Comparative Anatomy and Embryology.

11TH BIENNIAL PERIOD, 1927–29.—EDWARD BATTERSBY BAILEY, M.C., F.R.S., in recognition of his valuable contributions to the Geology of Scotland, two of which have recently appeared in the Transactions of the Society.

12TH BIENNIAL PERIOD, 1929–31.—CHARLES HENRY O'DONOGHUE, D.Sc., for his papers on the "Blood Vascular System," and for his earlier work on the "Morphology of the *corpus luteum*."

13TH BIENNIAL PERIOD, 1931–33.—GEORGE WALTER TYRRELL, A.R.C.S., D.Sc., for his contributions to the Geology and Petrology of Sub-Arctic and Sub-Antarctic Lands.

IV. GUNNING VICTORIA JUBILEE PRIZE.

1ST TRIENNIAL PERIOD, 1884–87.—Sir WILLIAM THOMSON, Pres. R.S.E., F.R.S., for a remarkable series of papers "on Hydrokinetics," especially on Waves and Vortices which have been communicated to the Society.

2ND TRIENNIAL PERIOD, 1887–90.—Professor P. G. TAIT, Sec. R.S.E., for his work in connection with the "Challenger" Expedition, and his other Researches in Physical Science.

3RD TRIENNIAL PERIOD, 1890–93.—ALEXANDER BUCHAN, Esq., LL.D., for his varied, extensive, and extremely important Contributions to Meteorology, many of which have appeared in the Society's publications.

4TH TRIENNIAL PERIOD, 1893–96.—JOHN AITKEN, Esq., for his brilliant Investigations in Physics, especially in connection with the Formation and Condensation of Aqueous Vapour.

1ST QUADRENNIAL PERIOD, 1896–1900.—Dr T. D. ANDERSON, for his discoveries of New and Variable Stars.

2ND QUADRENNIAL PERIOD, 1900–04.—Sir JAMES DEWAR, LL.D., D.C.L., F.R.S., etc., for his researches on the Liquefaction of Gases, extending over the last quarter of a century, and on the Chemical and Physical Properties of Substances at Low Temperatures: his earliest papers being published in the Transactions and Proceedings of the Society.

3RD QUADRENNIAL PERIOD, 1904–08.—Professor GEORGE CHRYSTAL, M.A., LL.D., for a series of papers on "Seiches," including "The Hydrodynamical Theory and Experimental Investigations of the Seiche Phenomena of Certain Scottish Lakes."

4TH QUADRENNIAL PERIOD, 1908–12.—Professor J. NORMAN COLLIE, Ph.D., F.R.S., for his distinguished contributions to Chemistry, Organic and Inorganic, during twenty-seven years, including his work upon Neon and other rare gases. Professor Collie's early papers were contributed to the Transactions of the Society.

5TH QUADRENNIAL PERIOD, 1912–16.—Sir THOMAS MUIR, C.M.G., LL.D., F.R.S., for his series of Memoirs upon "The Theory and History of Determinants and Allied Forms," published in the Transactions and Proceedings of the Society between the years 1872 and 1915.

6TH QUADRENNIAL PERIOD, 1916–20.—C. T. R. WILSON, Esq., F.R.S., in recognition of his important discoveries in relation to Condensation Nuclei, Ionisation of Gases and Atmospheric Electricity.

7TH QUADRENNIAL PERIOD, 1920–24.—Sir J. J. THOMSON, O.M., F.R.S., in recognition of his great discoveries in Physical Science.

8TH QUADRENNIAL PERIOD, 1924–28.—Professor E. T. WHITTAKER, F.R.S., in recognition of his distinguished contributions to Mathematical Science, and of his promotion of Mathematical Research in Scotland.

9TH QUADRENNIAL PERIOD, 1928–32.—Emeritus Professor Sir J. WALKER, F.R.S., for numerous contributions to Physical and General Chemistry.

V. JAMES SCOTT PRIZE.

1ST AWARD, 1918–22.—Professor A. N. WHITEHEAD, F.R.S., for his lecture delivered on June 5, 1922, on "The Relatedness of Nature."

2ND AWARD, 1922–27.—Sir JOSEPH LARMOR, M.A., D.Sc., LL.D., F.R.S., for his lecture delivered on July 4, 1927, on "The Grasp of Mind on Nature."

3RD AWARD, 1927–30.—Professor NIELS BOHR, for his lecture delivered on May 26, 1930, on "Philosophical Aspects of Atomic Theory."

4TH AWARD, 1930–33.—Professor Dr ARNOLD SOMMERFELD, for his lecture delivered on May 1, 1933, on "Ways to the Knowledge of Nature."

VI. BRUCE PRIZE.

1ST AWARD, 1926.—JAMES MANN WORDIE, M.A., for his Oceanographical and Geological work in both Polar Regions.

2ND AWARD, 1928.—H. U. SVERDRUP, for his contributions to the knowledge of the Meteorology, Magnetism, and Tides of the Arctic, as an outcome of his travels with the Norwegian Expedition in the "Maud" from 1918 to 1925.

3RD AWARD, 1930.—N. A. MACKINTOSH, M.Sc., A.R.C.S., for his researches into the Biology of Whales in the Waters of the Falkland Islands Dependencies.

4TH AWARD, 1932.—HENRY GINO WATKINS, for important contributions to the topography of Spitsbergen, Labrador, and East Greenland, and investigation of the Ice Cap of Greenland.

VII. BRUCE-PRELLER LECTURE FUND.

1ST AWARD, 1931.—Professor E. T. WHITTAKER, F.R.S., for his lecture, "James Clerk Maxwell and Mechanical Descriptions of the Universe."

2ND AWARD, 1933.—Professor C. H. LANDER, C.B.E., for his lecture on October 23, 1933, on "The Liquefaction of Coal."

ABSTRACT

OF

THE ACCOUNTS

OF

THE ROYAL SOCIETY OF EDINBURGH,

SESSION—1st October 1933 to 30th September 1934.

JAMES WATT, LL.D., W.S.,
Treasurer.

I. GENERAL FUND

CHARGE.

1. Arrears of Contributions at 30th September 1933			£119 14 0
2. Contributions for present Session:—			
1. 430 Fellows at £3, 3s. each		£1354 10 0	
2. Fees of Admission and Contributions of twenty-eight new Fellows at £6, 6s. each		176 8 0	
			1530 18 0
3. Extra Contributions for 1933–34 under Amended Law, No. 6:—			
1. Voluntary Contributions		£50 6 0	
2. Commutations		42 0 0	
			92 6 0
4. Interest received—			
a. Interest on £445, 10s. 3½% War Loan, 1952 (R. M. Smith Legacy), Untaxed.		£15 11 10	
b. Interest on £751, 16s. 3½% War Loan, 1952 (Special Subscription Fund), Untaxed.		26 6 4	
c. General—			
Interest on £7830 3½% War Loan, 1952, Untaxed	£274 1 0		
Interest on £2100 2½% Consolidated Stock, Untaxed.	52 10 0		
Interest on Deposit Receipts	7 16 9		
		334 7 9	
			376 5 11
5. Transactions and Proceedings sold			157 4 8
6. Grants—Annual Grant from Government		£600 0 0	
Grant from Royal Society, from Government Publication Grant		300 0 0	
			900 0 0
7. "Polar Year" Expenses recovered			38 15 2
Amount of the Charge .			**£3215 3 9**

DISCHARGE.

1. TAXES, INSURANCE, COAL AND LIGHTING:—				
Insurance				£21 7 9
Coal, etc., to 1st June 1934				45 0 0
Gas to 25th May 1934				2 0 10
Electric Light to 12th April 1934				12 6 10
Water, 1933–34				4 4 0
Equitable Life Assurance Co., Ltd., for Superannuation Scheme			£52 10 0	
Sun Life Assurance Society, for Superannuation Scheme			7 18 4	
Scottish Widows' Fund and Life Assurance Society, for Superannuation Scheme			18 6 8	
			£78 15 0	
Less—Received from Assistant Secretary		£17 10 0		
Received from Assistant Librarian		8 15 0		
			26 5 0	
				52 10 0
				£137 9 5
2. SALARIES:—				
General Secretary			£100 0 0	
Librarian and Assistant Secretary			350 0 0	
Assistant Librarian			175 0 0	
Office Keeper			151 12 0	
Treasurer's Clerk			35 0 0	
				811 12 0
3. EXPENSES OF TRANSACTIONS AND PROCEEDINGS:—				
a. TRANSACTIONS:—				
Neill & Co., Ltd., Printers			£527 19 2	
Hislop & Day, Ltd., Engravers			81 16 6	
The Zinco-Collotype Co.			123 10 0	
Macfarlane & Erskine, Printers			7 5 6	
			£740 11 2	
Less Receipts:—				
Grants from Carnegie Trustees and others towards the Papers: Prof. E. B. Bailey and Dr J. W. Weir, Dr Mary G. Calder, Dr Emily Dix, Dr W. J. Hamilton, Mr S. M. K. Henderson, Prof. T. J. Jehu and Dr R. M. Craig, Dr N. H. W. Maclaren and Prof. T. H. Bryce, Dr T. Nicol, Dr J. B. Simpson, Dr A. C. Stephen, Dr G. W. Tyrrell, and Dr S. Williams			153 9 11	
			£587 1 3	
b. PROCEEDINGS:—				
Neill & Co., Ltd., Printers		£698 8 6		
Hislop & Day, Ltd., Engravers		21 12 2		
		£720 0 8		
Less Receipts:—				
1. Revenue of Publication Fund	£70 11 10			
2. Grants from Carnegie Trustees and others towards the Papers: Prof. F. A. E. Crew, Dr P. Ch. Koller and Miss T. Townson; Dr G. W. Tyrrell and Dr K. S. Sandford	24 2 8			
		94 14 6		
			625 6 2	
				1212 7 5
Carry forward				£2161 8 10

Brought forward			£2161 8 10
4. **Books, Periodicals, Newspapers, etc.**:—			
James Thin, Bookseller	£269 14 5		
R. Grant & Son, Booksellers	4 1 4		
Robertson & Scott, News Agents	7 7 8		
Ray Society, Subscription	1 1 0		
Berwickshire Naturalists' Club, Do.	0 10 0		
Palæontographical Society, Do.	1 1 0		
History of Science Society, Do.	0 19 7		
Edinburgh and Leith Post-Office Directory, Ltd.	0 13 6		
Institution of Civil Engineers, for Abstracts	0 10 0		
Bombay Natural History Society, for *Journals*	4 17 0		
Scientific and Learned Societies' Year Book 1934	0 8 6		
Wm. Dawson & Sons, Ltd., *Journal of Botany*	12 11 9		
			303 15 9
5. **Other Payments**:—			
Neill & Co., Ltd., Printers	£114 17 6		
A. Cowan & Sons, Ltd.	17 10 9		
S. Duncan & Sons, Tailors (uniform)	9 9 0		
Macvitties, Guest & Co., Ltd.	42 8 0		
Andrew H. Baird	17 11 6		
Lindsay, Jamieson & Haldane, C.A., Auditors	10 10 0		
The Window Cleaning Co., Ltd.	15 18 0		
Orrock & Son, Ltd., Bookbinders	225 3 11		
Federated Superannuation System for Universities	5 0 0		
G. Waterston & Sons, Ltd.	22 2 11		
Telephone Accounts	15 1 3		
Roneo, Ltd.—Shelving, etc.	49 10 0		
W. S. Brown & Sons, Upholsterers, Shelving, etc.	63 14 5		
Wm. Blackwood & Sons, Ltd.	7 2 6		
Expenses of Delegate to Conference	5 10 0		
Miscellaneous Accounts under £5	28 0 3		
Charwoman	63 14 0		
Petty Expenses, Postages, Carriage, etc.	45 11 2		
Edward & Co., Electricians	8 17 5		
"Polar Year" Expenses	1 15 4		
			769 7 11
6. **Arrears of Contributions** outstanding at 30th September 1934:—			
Present Session	£81 18 0		
Previous Sessions	40 19 0		
			122 17 0
Amount of the Discharge			£3357 9 6

Amount of the Charge	£3215 3 9
Amount of the Discharge	3357 9 6
Excess of Discharge transferred to Special Subscription Fund	£142 5 9

SPECIAL SUBSCRIPTION FUND

To 30th September 1934.

Charge.

Total Subscriptions towards Fund		£1128 17 9
Less—Written off War Loan Investment		7 12 0
		£1121 5 9
Less—Transfers to General Fund to meet Deficits up to 30th September 1933	£436 1 4	
Add—Deficit for year to 30th September 1934	142 5 9	
		578 7 1
Amount of the Charge		£542 18 8

DISCHARGE.

BALANCE OF FUND—		
£751, 16s. 3½% War Loan, 1952		£751 16 0
Due by Treasurer		20 15 6
		£772 11 6
Less—Due to Union Bank of Scotland, Ltd., on Current Account		229 12 10
AMOUNT OF THE DISCHARGE		£542 18 8

WAR LOAN SUSPENSE ACCOUNT.

To 30th September 1934.

CHARGE.

Due by Union Bank of Scotland, Ltd., on Current Account at 30th September 1933	£111 1 6
Interest on Deposit Receipt (included in General Fund)	1 1 11
AMOUNT OF THE CHARGE	£112 3 5

DISCHARGE.

Due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£110 4 6
Transferred to General Fund	1 18 11
AMOUNT OF THE DISCHARGE	£112 3 5

II. KEITH FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£81 7 8
2. INTEREST RECEIVED:—		
On £650 3½% War Loan, 1952, Untaxed	£22 15 0	
On Deposit Receipts	0 14 9	
		23 9 9
		£104 17 5

DISCHARGE.

1. Alex. Kirkwood & Son, for Gold Medal	£20 0 0
Dr A. C. Mitchell, 1931–33 Award	40 0 0
	£60 0 0
2. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	44 17 5
	£104 17 5

III. NEILL FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£36 8 9
2. INTEREST RECEIVED:—		
On £300 3½% War Loan, 1952, Untaxed	£10 10 0	
On Deposit Receipts	0 5 11	
		10 15 11
		£47 4 8

DISCHARGE.

1. Alex. Kirkwood for Gold Medal	£20 0 0
Dr G. W. Tyrrell, 1931–33 Award	10 0 0
	£30 0 0
2. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	17 4 8
	£47 4 8

IV. MAKDOUGALL-BRISBANE FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£52 9 6
2. INTEREST RECEIVED:—		
On £400 3½% War Loan, 1952, Untaxed	£14 0 0	
On Deposit Receipts	0 11 3	
		14 11 3
		£67 0 9

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£67 0 9

V. MAKERSTOUN MAGNETIC METEOROLOGICAL OBSERVATION FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£106 14 8
2. INTEREST RECEIVED:—		
On £250 3½% War Loan, 1952, Untaxed	£8 15 0	
On Deposit Receipts	1 1 5	
		9 16 5
		£116 11 1

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£116 11 1

VI. GUNNING VICTORIA JUBILEE PRIZE FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£94 1 8
2. INTEREST RECEIVED:—		
On £599, 14s. 3½% War Loan, 1952, Untaxed	£20 19 10	
On Deposit Receipts	1 0 3	
		22 0 1
		£116 1 9

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£116 1 9

VII. JAMES SCOTT PRIZE FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£1 7 2
2. INTEREST RECEIVED:—		
On £247, 10s. 3½% War Loan, 1952, Untaxed . . .	£8 13 2	
On Deposit Receipts	0 0 6	
		8 13 8
		£10 0 10

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£10 0 10

VIII. PUBLICATION FUND

(COMPRISING PETER GUTHRIE TAIT MEMORIAL FUND AND DR JOHN AITKEN FUND)

Year to 30th September 1934.

CHARGE.

1. PETER GUTHRIE TAIT MEMORIAL FUND:—		
Year's Interest on £1550 3½% War Loan, 1952, Untaxed		£54 5 0
2. DR JOHN AITKEN FUND:—		
Year's Interest on £445, 10s. 3½% War Loan, 1952, Untaxed	£15 11 10	
Interest on Deposit Receipts	0 15 0	
		16 6 10
		£70 11 10

DISCHARGE.

Transferred to General Fund to meet Cost of Publications (see General Fund Discharge, No. 3*b*)	£70 11 10

IX. DR W. S. BRUCE MEMORIAL FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£22 3 3
2. INTEREST RECEIVED:—		
On £233 3½% Conversion Loan, 1961	£8 3 0	
On Deposit Receipts	0 4 11	
		8 7 11
		£30 11 2

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£30 11 2

X. BRUCE-PRELLER LECTURE FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£66 10 2
2. DIVIDEND AND INTEREST RECEIVED:—		
On £140, 9s. Royal Bank of Scotland Stock, less Tax £5, 15s. 5d.	£18 4 1	
On Deposit Receipts	0 6 3	
		18 10 4
3. REPAYMENT of Income Tax for year to December 1933		5 19 4
		£90 19 10

DISCHARGE.

1. Prof. C. H. Lander, 1930–32 Award	£40 0 0
2. BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	50 19 10
	£90 19 10

XI. DR DAVID ANDERSON-BERRY FUND

Year to 30th September 1934.

CHARGE.

1. BALANCE of Revenue due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1933		£9 16 2
2. INTEREST RECEIVED:—		
On £1528, 0s. 4d. Local Loans 3% Stock, *less* Tax £11, 3s. 3d.	£34 13 5	
On Deposit Receipts	0 5 0	
		34 18 5
3. Income Tax repaid for year to 5th April 1934		11 9 0
		£56 3 7

DISCHARGE.

BALANCE due by Union Bank of Scotland, Ltd., on Deposit Receipt at 30th September 1934	£56 3 7

STATE OF THE FUNDS BELONGING TO THE ROYAL SOCIETY OF EDINBURGH

As at 30th September 1934.

1. GENERAL FUND—

1. £7830 3½% War Loan, 1952		£7830 0 0
2. £2100 2½% Consolidated Stock at 53%		1113 0 0
3. £445, 10s. 3½% War Loan, 1952. Robert Mackay Smith, Legacy		445 10 0
4. Arrears of Contributions, as per preceding Abstract of Accounts		122 17 0
5. Balance of Special Subscription Fund—		
£751, 16s. 3½% War Loan, 1952	£751 16 0	
Cash due by Treasurer	20 15 6	
	£772 11 6	
Less—Cash due to Union Bank of Scotland, Ltd., on Current Account	229 12 10	
		542 18 8
6. War Loan Suspense Account—		
Due by Union Bank of Scotland, Ltd., on Deposit Receipt		110 4 6
AMOUNT		£10,164 10 2

Exclusive of Library, Museum, Pictures, etc., and Furniture in the Society's Rooms at George Street, Edinburgh.

2. KEITH FUND—

1. £650 3½% War Loan, 1952		£650 0 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		44 17 5
AMOUNT		£694 17 5

3. NEILL FUND—

1. £300 3½% War Loan, 1952		£300 0 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		17 4 8
AMOUNT		£317 4 8

4. MAKDOUGALL-BRISBANE FUND—

1. £400 3½% War Loan, 1952		£400 0 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		67 0 9
AMOUNT		£467 0 9

5. MAKERSTOUN MAGNETIC METEOROLOGICAL OBSERVATION FUND—

1. £250 3½% War Loan, 1952		£250 0 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		116 11 1
AMOUNT		£366 11 1

6. GUNNING VICTORIA JUBILEE PRIZE FUND—Instituted by Dr Gunning of Edinburgh and Rio de Janeiro—

1. £599, 14s. 3½% War Loan, 1952		£599 14 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		116 1 9
AMOUNT		£715 15 9

7. JAMES SCOTT PRIZE FUND—

1. £247, 10s. 3½% War Loan, 1952		£247 10 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		10 0 10
AMOUNT		£257 10 10

8. PUBLICATION FUND—

(COMPRISING PETER GUTHRIE TAIT MEMORIAL FUND AND DR JOHN AITKEN FUND)

1. PETER GUTHRIE TAIT MEMORIAL FUND:—		
£1550 3½% War Loan, 1952		£1550 0 0
2. DR JOHN AITKEN FUND:—		
£445, 10s. 3½% War Loan, 1952	£445 10 0	
Deposit Receipt with Union Bank of Scotland, Ltd.	71 6 1	
		516 16 1
AMOUNT		£2066 16 1

9. DR W. S. BRUCE MEMORIAL FUND—

1. £233 3½% Conversion Loan, at 72⅞% (cost price)		£169 15 11
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		30 11 2
AMOUNT		£200 7 1

10. BRUCE-PRELLER LECTURE FUND—

1. £140, 9s. Royal Bank of Scotland, Stock taken over at 350%		£491 11 6
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		50 19 10
AMOUNT		£542 11 4

11. DR DAVID ANDERSON-BERRY FUND—

1. £1528, 0s. 4d. Local Loans 3% Stock at 65$\frac{7}{16}$% (cost price)		£1000 0 0
2. Balance due by Union Bank of Scotland, Ltd., on Deposit Receipt		56 3 7
AMOUNT		£1056 3 7

Note 1.—As previously, 3½% War Loan, 1952, has been uniformly valued at par in the above State of Funds.

2.—Under the Will of the late Prof. Charles Piazzi Smyth and his wife, the Society will, on the expiry of certain liferents, become entitled to payment of the residue to be applied as set out in the will.

EDINBURGH, 11*th October* 1934.—We have examined the preceding Accounts of the Treasurer of the Royal Society of Edinburgh for the Session 1933–1934, and have found them to be correct. The securities for the various Investments, as noted in the foregoing Statement of Funds, have been verified by us at 30th September 1934.

LINDSAY, JAMIESON & HALDANE, C.A.,
Auditors.

VOLUNTARY CONTRIBUTORS who have made a Single Payment under Law VI (end of para. 3), up to 30th September 1934.

	£	s.	d.
Sir AUCKLAND GEDDES,	£10	10	0
WILLIAM GENTLE, Esq.,	10	10	0
	£21	0	0
Carried forward,	£21	0	0
Dr W. J. MALONEY,	10	10	0
Dr J. H. H. PIRIE,	10	10	0
Total,	£42	0	0

VOLUNTARY CONTRIBUTORS under Law VI (end of para. 3), to 30th September 1934.

	£	s.	d.
Col. A. F. APPLETON,	£1	1	0
Sir JAMES BARR,	1	1	0
Sir T. HUDSON BEARE,	1	1	0
F. A. BLACK, Esq.,	1	1	0
Professor F. O. BOWER, F.R.S.,	1	1	0
Principal O. C. BRADLEY,	1	1	0
Dr G. S. BROCK,	1	1	0
J. W. BUTTERS, Esq.,	1	1	0
W. L. CALDERWOOD, Esq.,	1	1	0
Professor E. W. CARLIER,	1	1	0
Professor E. G. COKER,	1	1	0
Professor J. N. COLLIE, F.R.S.,	1	1	0
D. B. DOTT, Esq.,	1	1	0
Dr JOHN EYRE,	5	5	0
E. OSWALD FERGUS, Esq.,	1	1	0
Dr R. A. FLEMING,	1	1	0
J. S. FORD, Esq.,	1	1	0
Dr A. GALT,	1	1	0
Professor J. STRICKLAND GOODALL,	1	1	0
Dr W. D. HENDERSON,	1	1	0
Dr E. M. HORSBURGH,	1	1	0
Dr W. F. HUME,	1	1	0
	£27	6	0
Carried forward,	£27	6	0
Professor J. GRAHAM KERR, F.R.S.,	1	1	0
ARCHIBALD KING, Esq.,	1	1	0
F. H. LIGHTBODY, Esq.,	1	1	0
Dr P. M'BRIDE (1932-33, 1933-34),	2	2	0
JAMES A. MACDONALD, Esq.,	1	1	0
Sir W. LESLIE MACKENZIE,	1	1	0
Dr H. R. MILL,	1	1	0
R. C. MOSSMAN, Esq.,	1	1	0
Sir THOMAS MUIR, F.R.S.,	1	1	0
J. T. PEARCE, Esq.,	1	1	0
Professor W. PEDDIE (1932-33, 1933-34),	2	0	0
Professor A. G. PERKIN, F.R.S.,	1	1	0
A. G. RAMAGE, Esq.,	1	1	0
Professor R. A. ROBERTSON,	1	1	0
EDWARD SMART, Esq.,	1	1	0
Dr H. F. STOCKDALE,	1	1	0
G. SUTHERLAND THOMSON, Esq.,	1	1	0
R. TATLOCK THOMSON, Esq.,	1	1	0
Sir JAMES WALKER, F.R.S.,	1	1	0
J. C. WRIGHT, Esq.,	1	1	0
Total,	£50	6	0

	£	s.	d.
Single payment,	£42	0	0
Other payments,	50	6	0
Total,	£92	6	0

THE COUNCIL OF THE SOCIETY.

22nd October 1934.

President.

Professor D'ARCY WENTWORTH THOMPSON, C.B., D.Litt., D.Sc., LL.D., F.R.S.

Vice-Presidents.

Principal Sir THOMAS H. HOLLAND, K.C.S.I., K.C.I.E., D.L., Hon. D.Sc., LL.D., F.R.S.
Professor C. G. DARWIN, M.A., F.R.S.
Professor R. A. SAMPSON, M.A., D.Sc., LL.D., F.R.S.
Principal O. CHARNOCK BRADLEY, M.D., D.Sc.
Professor P. T. HERRING, M.D., F.R.C.P.E.
The Most Hon. THE MARQUIS OF LINLITHGOW, K.T., G.C.I.E., D.L.

General Secretary.

Professor J. H. ASHWORTH, D.Sc., F.R.S.

Secretaries to Ordinary Meetings.

Professor F. A. E. CREW, M.D., D.Sc., Ph.D.
Professor J. P. KENDALL, M.A., D.Sc., F.R.S.

Treasurer.

JAMES WATT, W.S., LL.D.

Curator of Library and Museum.

LEONARD DOBBIN, Ph.D.

Councillors.

Professor E. B. BAILEY, M.C., M.A., F.R.S.

Professor J. C. BRASH, M.C., M.A., M.D.

Professor A. J. CLARK, M.C., B.A., M.D., F.R.S.

Professor A. G. OGILVIE, O.B.E., M.A., B.Sc.

Professor E. M. WEDDERBURN, O.B.E., M.A., D.Sc., LL.B., W.S.

Lt.-Col. A. G. M'KENDRICK, M.B., D.Sc., F.R.C.P.E.

Emeritus Professor JAMES MACKINNON, M.A., Ph.D., LL.D.

Professor WILLIAM PEDDIE, D.Sc.

ALEXANDER C. AITKEN, M.A., D.Sc.

Principal J. C. SMAIL, A.Inst.E.E.

Sir HAROLD J. STILES, K.B.E., M.B., F.R.C.S.E., LL.D.

Professor JOHN WALTON, M.A., D.Sc.

Office Staff.

Assistant Secretary and Librarian, G. A. STEWART.
Assistant Librarian, R. J. B. MUNRO.
Housekeeper, SAMUEL HEDDLE.

PATRON.

HIS MOST EXCELLENT MAJESTY THE KING.

FELLOWS OF THE SOCIETY,

Corrected to 22nd October 1934.

N.B.—*Those marked* * *are Annual Contributors.*
" " † *have commuted Voluntary Contribution* (*see 3rd Paragraph, Law VI*).

M-B.	prefixed to a name indicates that the Fellow has received a Makdougall-Brisbane Medal.
K.	" " " " Keith Medal.
N.	" " " " Neill Medal.
V. J.	" " " " the Gunning Victoria Jubilee Prize.
B.	" " " " Bruce Medal.
B-P.	" " " " Bruce-Preller Lectureship.
C.	" " " has contributed one or more Communications to the Society's TRANSACTIONS OR PROCEEDINGS.

Date of Election			Service on Council, etc.
1922		* Abernethy, Charles Lawrence, M.A., B.Sc., Research Physicist, "Exnaböe," Craiglockhart Avenue, Slateford, Edinburgh 11	
1925	M-B. C.	* Aitken, Alexander Craig, M.A., D.Sc., Lecturer in Actuarial Science, University of Edinburgh (16 Chambers Street). 54 Braid Road, Edinburgh 10	1934–
1889		† Alison, John, M.A., LL.D., formerly Head Master, George Watson's College. 126 Craiglea Drive, Edinburgh 10	
1927	C.	* Allan, Douglas Alexander, D.Sc., Director, City of Liverpool Public Museums, William Brown Street, Liverpool	
1920	C. M-B.	* Allen, Herbert Stanley, M.A. (Cantab.), D.Sc. (London), F.R.S., Professor of Natural Philosophy, University of St Andrews	1921–24.
1920	C.	* Anderson, Ernest Masson, M.A., D.Sc., F.G.S., 50 Greenbank Crescent, Edinburgh	
1905		Anderson, William, M.A., Head Science Master, George Watson's College, Edinburgh. 6 Lockharton Crescent, Edinburgh 11	
1905		Andrew, George, M.A., B.A., H.M.I.S., Royal Technical College, George Street, Glasgow. Hamewith, Kilmacolm, Renfrewshire	
1930		* Annan, William, M.A., C.A., Professor of Accounting and Business Method, University of Edinburgh (South Bridge). Tofthill, Ferry Road West, Edinburgh 5	
1915		Anthony, Charles, M.Inst.C.E., M.Am.Soc.C.E., F.C.S., Spring Croft, Les Croutes, St Peter Port, Guernsey, Channel Islands	
1906		Appleton, Colonel Arthur Frederick, F.R.C.V.S., Nutwell, 34 Shortlands Road, Shortlands, Kent	
1910	C.	Archibald, E. H., B.Sc., Professor of Chemistry, University of British Columbia, Vancouver, Canada	
1933		* Arnot, Frederick Latham, B.Sc. (Sydney), Ph.D. (Cantab.), Lecturer in Natural Philosophy, University of St Andrews. Lindatham, Melville Grove, Largo Road, St Andrews	
1921		* Arthur, William, M.A., Lecturer in Mathematics, University of Glasgow. 148 Carmunnock Road, Cathcart, Glasgow	
1911	C. K.	* Ashworth, James Hartley, D.Sc., F.R.S. (GENERAL SECRETARY), Professor of Natural History, University of Edinburgh (West Mains Road). "Hillbank," Grange Loan, Edinburgh 9	1912–14, 1915–18, 1927–30. Sec. 1918–23. V-P 1923–26, 1930–33. Gen. Sec. 1933–
1920		* Bagnall, Richard Siddoway, Hon. D.Sc., F.R.E.S. (*address not known*).	
1920	C. N.	* Bailey, Edward Battersby, M.C., M.A., F.R.S., F.G.S., Professor of Geology, University of Glasgow	1932–

Date of Election			Service on Council, etc.
1896	C.	† Baily, Francis Gibson, M.A., M.Inst.E.E., Emeritus Professor of Electrical Engineering, Heriot-Watt College, Edinburgh. Newbury, Juniper Green, Midlothian	1909–12, 1920–23. V-P 1929–32.
1934		* Bain, David, M.Sc. (Manch.), D.Sc. (Edin.), Lecturer in Technical Chemistry, University of Edinburgh (West Mains Road). 87 Cluny Gardens, Edinburgh 10	
1931	C.	* Bain, William Alexander, Ph.D., Lecturer in Physiology, School of Medicine, University of Leeds. 26 Weetwood Road, Headingley, Leeds 6	
1931		* Baird, William Macdonald, Fellow and Past President of the Faculty of Surveyors of Scotland, F.S.A.Scot., J.P. Dalveen, Barnton Avenue, Davidson's Mains, Edinburgh 4	
1921		* Baker, Bevan Braithwaite, M.A., D.Sc., Professor of Mathematics, Royal Holloway College, Englefield Green, London	
1928	C.	* Baker, Edwin Arthur, D.Sc. (Edin.), Assistant at the Royal Observatory, Edinburgh. 17 Ladysmith Road, Edinburgh 9	
1905	C.	Balfour-Browne, William Alexander Francis, M.A., F.Z.S., F.L.S., F.R.E.S., F.R.M.S., Barrister-at-Law, formerly Professor of Entomology, Imperial College of Science, London. Winscombe Court, Winscombe, Somerset, and 17 Langham Mansions, Earls Court Square, London, S.W. 5	
1933		* Banerjee, Prabodh Chandra, L.R.C.P.E., L.R.C.S.E., F.R.F.P.S.G., F.A.C.S., Major, I.M.S. C/o Lloyds Bank, Ltd., 101–1 Clive Street, Calcutta, India	
1928		Barbour, George Brown, M.A. (Edin.), M.A. (Cantab.), Ph.D., F.G.S., 4 Clareville Grove, London, S.W. 7	
1886		Barclay, A. J. Gunion, M.A., 3 Chandos Avenue, Oakleigh Park, London, N.	
1903		Bardswell, Noël Dean, M.V.O., M.D., M.R.C.P. (Ed. and Lond.), New County Hall, Westminster Bridge Road, London, S.E. 1	
1922		* Barger, George, M.A., D.Sc., Dr *h. c.* (Padua), Hon. D.Sc. (Liverp.), Hon. M.D. (Heidelberg), LL.D. (Michigan), F.R.S., Hon. Mem. Nederl. Chem. Vereen.; Corr. Mem. Bayerische Akad. d. Wissensch. München and Ges. d. Wissensch. Göttingen, Professor of Chemistry (Medical), University of Edinburgh (Teviot Place). 48 St Alban's Road, Edinburgh 9	1925–28.
1929		* Barker, Sydney George, O.B.E., D.I.C., F.Inst.P., formerly Director of Research, Wool Industries Research Association, Torridon, Leeds	
1914	C.	* Barkla, Charles Glover, M.A., D.Sc., F.R.S., Professor of Natural Philosophy, University of Edinburgh (Drummond Street), Nobel Laureate, Physics, 1917. The Hermitage of Braid, Edinburgh	1915–18. 1924–27.
1925		* Barlow, Thomas William Naylor, O.B.E., M.R.C.S., D.P.H., Barrister-at-Law, 23 North Drive, New Brighton, Cheshire	
1927		* Barnett, John, F.F.A., C.A., Scottish Widows' Fund Life Assurance Society, 9 St Andrew Square, Edinburgh 2	
1904		Barr, Sir James, C.B.E., M.D., LL.D., F.R.C.P., Hindhead Brae, Hindhead, Surrey	
1921		* Bartholomew, John, M.C., M.A., F.R.G.S., Geographical Institute, Duncan Street, Edinburgh. 19 George Square, Edinburgh 8	1925–28.
1932	C.	* Barton-Wright, Eustace Cecil, M.Sc. (Lond.), Camping Close, Harston, Cambridge	
1927		* Bastow, Stephen Everard, M.Inst.E.E., M.Inst.Min.E., Managing Director, Bruce Peebles & Co., Ltd., Edinburgh. Northwood, Russell Place, Trinity, Edinburgh 5	
1929		* Bath, Frederick, Ph.D., Lecturer in Mathematics, University of St Andrews, Assistant to the Professor of Mathematics, University College, Dundee	
1913		† Beard, Joseph, F.R.C.S.E., M.R.C.S., L.R.C.P., D.P.H. (Cantab.), formerly Medical Officer of Health, City of Carlisle. 8 Carlton Gardens, Carlisle	
1888		Beare, Sir Thomas Hudson, Kt., B.A., B.Sc., M.Inst.C.E., Hon. M.I.Mech.E., J.P., D.L., Professor of Engineering, University of Edinburgh (Sanderson Engineering Laboratory, Mayfield Road). 10 Regent Terrace, Edinburgh 7	1907–09. V-P 1909–15, 1923–26.
1897	C.	Beattie, Sir John Carruthers, K.B., D.Sc., LL.D., Vice-Chancellor and Principal, The University, Cape Town	
1893	C. M-B.	Becker, Ludwig, Ph.D., Regius Professor of Astronomy, University of Glasgow. The Observatory, Dowanhill, Glasgow	
1933		* Begg, James Livingstone, F.G.S. (Treasurer, Geological Society of Glasgow). Elms, Mount Vernon, Glasgow	
1916		* Bell, Robert John Tainsh, M.A., D.Sc., LL.D. (Glas.), Professor of Mathematics, University of Otago, Dunedin, New Zealand	

Date of Election			Service on Council, etc.
1929		* Bennet, George, A.H.-W.C., B.Sc., A.M.I.Mech.E., Lecturer in Mechanical Engineering, Heriot-Watt College. 68 Arden Street, Edinburgh 10	
1893	C.	Berry, Sir George A., M.B., C.M., LL.D., F.R.C.S.E., King's Knoll, North Berwick	1916–19. V-P 1919–22.
1897	C.	Berry, Richard J. A., M.D., F.R.C.S.E., Director of Medical Services, Stoke Park Colony, Stapleton, Bristol. Rufford, Canford Lane, Westbury-on-Trym, Bristol	
1932		* Bhatia, Sohan Lal, M.C., M.A., M.D. (Cantab.), M.R.C.P., Major, I.M.S., Professor of Physiology and Dean, Grant Medical College, Bombay. Two Gables, Mount Pleasant Road, Malabar Hill, Bombay, India	
1880	C.	Birch, de Burgh, C.B., M.D., Emeritus Professor of Physiology, University of Leeds	
1931	C.	* Black, Thomas Purves, M.A. (Edin.), B.Sc. (Lond.), Ph.D. (Edin.), Headmaster, Bellevue Technical and Commercial School, Edinburgh. 32 Eastfield, Joppa 6	
1918		* Blight, Francis James, formerly Chairman and Managing Director, Charles Griffin & Co., Ltd., Publishers. Belstone Tor, 37 Parkside, Mill Hill, London, N.W. 7	
1933		* Bolam, Thomas Robert, M.Sc. (Bristol), D.Sc. (Edin.), Lecturer in Chemistry, University of Edinburgh (West Mains Road). 8 Wilton Road, Edinburgh 9	
1894		Bolton, Herbert, D.Sc., F.G.S., F.Z.S., formerly Director, Bristol Museum and Art Gallery, Bristol. 318 Tilehurst Road, Reading, Berks	
1915		† Boon, Alfred Archibald, D.Sc., B.A., F.I.C., Emeritus Professor of Chemistry, Heriot-Watt College, Edinburgh	
1925		* Borthwick, Albert William, O.B.E., D.Sc., Professor of Forestry, University of Aberdeen	
1925		* Bose, Sahay Ram, M.A., D.Sc., F.L.S., Professor of Botany, Carmichael Medical College, Belgachia, Calcutta, India	
1886	C. N.	Bower, Frederick Orpen, M.A., D.Sc., LL.D., F.R.S., F.L.S., Emeritus Regius Professor of Botany, University of Glasgow. 2 The Crescent, Ripon, Yorks	1887–90, 1893–96, 1907–09, 1917–19. V-P 1910–16. P 1919–24.
1924		* Bowman, Alexander, D.Sc., formerly Scientific Superintendent, Marine Laboratory, Fishery Board for Scotland, Torry, Aberdeen	
1903	C.	Bradley, O. Charnock, M.D., D.Sc. (Vice-President), Principal, Royal (Dick) Veterinary College, Edinburgh 9	1907–10, 1915–17. V-P 1934–
1926		* Braid, Kenneth William, M.A. (Cantab.), B.Sc., Professor of Botany, West of Scotland Agricultural College, 6 Blythswood Square, Glasgow	
1907		† Bramwell, Edwin, M.D., F.R.C.P.E., F.R.C.P., Professor of Clinical Medicine, University of Edinburgh (Royal Infirmary). 23 Drumsheugh Gardens, Edinburgh 3	
1932		* Brash, James Couper, M.C., M.A., M.B., Ch.B. (Edin.), M.D. (Birm.), Professor of Anatomy, University of Edinburgh (Teviot Place)	1932–
1918		* Bremner, Alexander, M.A., D.Sc., Headmaster, Demonstration School, Training Centre, Aberdeen. 13 Belgrave Terrace, Aberdeen	
1916	C.	* Briggs, Henry, O.B.E., D.Sc., Ph.D., A.R.S.M., James A. Hood Professor of Mining, University of Edinburgh (79 Grassmarket, Edinburgh 1). 12 Gordon Terrace, Edinburgh 9	1923–26.
1895		Bright, Sir Charles, M.Inst.C.E., M.Inst.E.E., F.R.Ae.S., F.Inst.Radio E., Little Brewers', Hatfield Heath, Harlow, Essex	
1893		Brock, G. Sandison, M.D., F.R.C.P.E., 53 Cheniston Gardens, Kensington, London, W. 8	
1901	C.	Brodie, W. Brodie, M.D., Camden House, Bletchingley, Surrey	
1934		* Brough, Patrick, M.A., B.Sc. (Glas.), D.Sc. (Sydney), Lecturer in Botany, University of Sydney, N.S.W.	
1907		Brown, Alexander, M.A., B.Sc., Professor of Applied Mathematics, University, Cape Town	

Date of Election			Service on Council, etc.
1928		* Brown, Hugh Wylie, F.I.A., F.F.A., 1 Cobden Crescent, Edinburgh 9	
1885		Brown, J. Macdonald, M.D., F.R.C.S., Oriental Club, Hanover Square, London, W. 1	
1924	C.	* Brown, Thomas Arnold, M.A., B.Sc., Professor of Mathematics, University College, Exeter	
1923		* Brown, Walter, M.A., B.Sc., Professor of Mathematics, University, Hong Kong, China	
1921		* Bruce, Alexander, B.Sc. (Edin.), Government Agricultural Chemist and City Analyst, The Laboratory, Turret Road S., Colombo, Ceylon	
1912		* Bruce, Alexander Ninian, D.Sc., M.D., 8 Ainslie Place, Edinburgh 3	
1927		* Bryce, David Lawrence, The Ascension Vicarage, Thornhill Avenue, Plumstead, London, S.E. 18	
1898	C. K.	† Bryce, Thomas Hastie, M.A., M.D. (Edin.), F.R.S., Professor of Anatomy, University of Glasgow. 2 The College, Glasgow	1911–14, 1922–25. V-P 1925–28.
1887		† Burnet, Sir John James, R.A., R.S.A., LL.D., Killermont, Rowledge, Farnham, Surrey	
1888		Burns, Rev. Thomas, C.B.E., D.D., J.P., F.S.A.Scot., Minister of Lady Glenorchy's Parish Church. Croston Lodge, Chalmers Crescent, Edinburgh 9	
1917		* Burnside, George Barnhill, M.Inst.Mech.E., Fairhill, Dullatur	
1930	C.	* Burt, David Raitt Robertson, B.Sc. (St Andrews), F.L.S., Lecturer in Zoology, Ceylon University College, Colombo	
1896		Butters, John W., M.A., B.Sc., formerly Rector of Ardrossan Academy. 116 Comiston Drive, Edinburgh 10	
1929	C.	* Calder, Alexander, Ph.D., Assistant Marketing Officer, Pig Marketing Board. C/o Watt, 37 Victoria Park Gardens, Broomhill, Glasgow	
1910		Calderwood, Rev. Robert Sibbald, D.D., Minister of Cambuslang. The Old Manse, Cambuslang, Lanarkshire	
1893	C.	Calderwood, W. L., I.S.O., formerly Inspector of Salmon Fisheries of Scotland. New Club, Princes Street, Edinburgh	1923–26.
1926	C.	* Cameron, Alfred E. Henderson, M.A., D.Sc. (Aberd.), Lecturer in Entomology, Department of Zoology, University of Edinburgh (West Mains Road). 8 West Savile Road, Edinburgh 9	
1933		* Cameron, Finlay James, F.F.A., F.I.A., General Manager, Caledonian Insurance Company. Beech Knowe, Barnton, near Edinburgh	
1905	C.	Cameron, John, M.D., D.Sc., M.R.C.S., formerly Professor of Anatomy, Dalhousie University, Halifax, Nova Scotia. Balmashanner, Grove Road, East Cliff, Bournemouth	
1921		* Campbell, Andrew, Advisory Chemist, c/o Burmah Oil Co., Ltd., Research Laboratory, Fairlawn, Honor Oak Road, Forrest Hill, London, S.E. 68 Albemarle Road, Beckenham, Kent	
1918		* Campbell, John Menzies, D.D.S. (Toronto), L.D.S. (Glas.), L.D.S. (Ontario), F.I.C.D., 14 Buckingham Terrace, Glasgow, W.	
1915	C. N.	* Campbell, Robert, M.A., D.Sc., F.G.S., Reader in Petrology, University of Edinburgh (Grant Institute of Geology, West Mains Road). Maryton, Colinton	1920–23.
1927	C.	* Cannon, Herbert Graham, M.A., Sc.D. (Cantab.) D.Sc. (Lond.), F.L.S., Beyer Professor of Zoology, University of Manchester	
1899	C.	Carlier, Edmund W. W., B. ès Sc., M.Sc., M.D., F.R.E.S., Emeritus Professor of Physiology, University of Birmingham. Morningside, Dorridge, near Birmingham	
1910		Carnegie, Col. David, C.B.E., M.Inst.C.E., J.P., The Haven, Seasalter, Whitstable	
1931		* Carroll, John Anthony, M.A., Ph.D. (Cantab.), Professor of Natural Philosophy, University of Aberdeen. Marischal College, Aberdeen	
1920	C.	* Carruthers, R. G., F.G.S., District Geologist, H.M. Geological Survey, High Barn, Stocksfield-on-Tyne	
1905	C.	Carse, George Alexander, M.A., D.Sc., Reader in Natural Philosophy, University of Edinburgh (Drummond Street). 3 Middleby Street, Edinburgh 9	
1901		Carslaw, Horatio Scott, M.A., Sc.D. (Cantab.), D.Sc., LL.D. (Glas.), formerly Professor of Mathematics, University of Sydney, New South Wales	
1933		* Carswell, John Irvine, B.Sc., A.M.Inst.C.E., A.M.Inst.Mech.E., Lecturer in Engineering, University of Edinburgh (Sanderson Engineering Laboratory, Mayfield Road). 43 Mansionhouse Road, Edinburgh 9	
1925		* Carter, George Stuart, M.A., Ph.D., Corpus Christi College, Cambridge	

Date of Election			Service on Council, etc.
1898		Carus-Wilson, Cecil, J.P., F.G.S., F.R.G.S., Altmore, Waldegrave Park, Strawberry Hill, Twickenham, and Sandacres Lodge, Parkstone, Dorset	
1932		* Cathcart, Edward Provan, C.B.E., M.D., D.Sc., LL.D., F.R.S., Professor of Physiology, University of Glasgow. 28 Hillhead Street, Glasgow	
1899		Chatham, James, Actuary, Ladieside, Melrose	
1932	C.	* Childe, Vere Gordon, B.A., B.Litt., F.R.A.I., F.S.A., Professor of Prehistoric Archæology, University of Edinburgh (14 Chambers Street)	
1925	C.	* Chumley, James, M.A., Ph.D., Lecturer in Oceanography, Department of Zoology, University of Glasgow. Thalassa, Thorn Drive, Bearsden, Dumbartonshire	
1928	C.	* Clark, Alfred Joseph, M.C., B.A., M.D., F.R.S., Professor of Materia Medica, University of Edinburgh (Teviot Place). 67 Braid Avenue, Edinburgh 10	1932–
1933		* Clark, Arthur Melville, M.A. (Edin.), D. Phil. (Oxon.), Lecturer in English Literature, University of Edinburgh. 7 Harrison Road, Edinburgh 11	
1891		Clark, John Brown, M.A., LL.D., J.P., formerly Head Master of George Heriot's School. Garleffin, 146 Craiglea Drive, Edinburgh 10	1928–1931. V.-P. 1931–34.
1932		* Clark, Sir Thomas, Bart., Publisher, Head of T. & T. Clark, Ltd. 6 Wester Coates Road, Edinburgh 12	
1903		Clarke, William Eagle, I.S.O., LL.D., F.L.S., Honorary Supervisor of the Bird Collection and formerly Keeper of the Natural History Collections, Royal Scottish Museum, Edinburgh	
1909		Clayton, Thomas Morrison, M.D., D.Hy., B.Sc., D.P.H., Medical Officer of Health, Greenesfield House, Gateshead-on-Tyne	
1932		* Clouston, David, M.A., B.Sc. (Agric.), D.Sc., C.I.E., formerly Director, Imperial Agricultural Research Institute, Pusa. Forthview, Boswall Road, Edinburgh 5	
1904	C.	Coker, Ernest George, M.A. (Cantab.), D.Sc. (Edin.), Hon. D.Sc. (Sydney and Louvain), M.Sc. (McGill), F.R.S., M.Inst.C.E., M.I.Mech.E., formerly Kennedy Professor of Civil and Mechanical Engineering. Engineering Laboratories, 14 Connaught Avenue, Chingford, London, E. 4	
1904		Coles, Alfred Charles, M.D., D.Sc., York House, Poole Road, Bournemouth, W.	
1888	V. J. C.	Collie, John Norman, Ph.D., D.Sc., LL.D., F.R.S., F.C.S., F.I.C., Emeritus Professor of Organic Chemistry, University College, Gower Street, London. 20 Gower Street, London, W.C. 1	
1909	C.	Comrie, Peter, M.A., B.Sc., LL.D., formerly Rector, Leith Academy. 19 Craighouse Terrace, Edinburgh 10	
1924	C.	* Copson, Edward Thomas, M.A., D.Sc., Assistant Professor of Mathematics, Royal Naval College, Greenwich. 62 Coleraine Road, Blackheath, London, S.E. 3	
1928		* Coutie, Rev. Alexander, Ph.D., 13 Mayfield Gardens, Edinburgh 9	
1914		* Coutts, William Barron, M.A., B.Sc., Senior Lecturer in Range Finding and Optics, Military College of Science, Red Barracks, Woolwich, S.E. 18. 11 Coleraine Road, Blackheath, S.E. 3	
1911		* Cowan, Alexander, Papermaker, Valleyfield, Penicuik, Midlothian	
1931		* Cowan, John Macqueen, M.A., D.Sc. (Edin.), B.A. (Oxon.), F.L.S., Assistant Keeper, Royal Botanic Garden, Edinburgh. 17 Inverleith Place, Edinburgh 4	
1916	C.	† Craig, E. H. Cunningham, B.A. (Cantab.), Geologist and Mining Engineer, The Dutch House, Beaconsfield	
1908		Craig, James Ireland, M.A., B.A., Woolwich House, The Drive, Sydenham, London, S.E. 26. (At present—Turf Club, Cairo)	
1925	C. K.	* Craig, Robert Meldrum, M.A., D.Sc., F.G.S., Lecturer in Economic Geology, University of Edinburgh (Grant Institute of Geology, West Mains Road)	
1933		* Craig-Bennett, Arthur Lancelot, M.A., Ph.D. (Cantab.), Lecturer in Zoology, University of Edinburgh (West Mains Road). 27 Grange Loan, Edinburgh 9	
1903		Crawford, Lawrence, M.A., D.Sc., Professor of Pure Mathematics, University, Cape Town	
1922	C.	* Crew, Francis Albert Eley, M.D., D.Sc., Ph.D. (SECRETARY TO ORDINARY MEETINGS), Professor of Animal Genetics and Director of the Institute of Animal Genetics, University of Edinburgh (West Mains Road). 10 Salisbury Road, Edinburgh 9	1928–31. Sec. 1931–

Date of Election			Service on Council, etc.
1931		* Crichton, John, M.A., B.Sc. (Edin.), Rayleigh House, The Observatory, Eskdalemuir, Langholm	
1870		Crichton-Browne, Sir Jas., Kt., M.D., LL.D., D.Sc., F.R.S., Vice-President and Treasurer of the Royal Institution of Great Britain. 45 Hans Place, London, S.W. 1	
1929		* Cruickshank, Ernest William Henderson, M.D., D.Sc., Ph.D., Professor of Physiology, Dalhousie University, Halifax, Nova Scotia	
1914		* Cumming, Alexander Charles, O.B.E., D.Sc., Roselands, Crescent Road, Blundell Sands, Liverpool	
1928		* Cumming, William Murdoch, D.Sc. (Glas.), F.I.C., M.Inst.Chem.E., "Young" Professor of Technical Chemistry, Royal Technical College, Glasgow. "Bonnieblink," 4 Newlands Road, Newlands, Glasgow, C. 1	
1917		* Cunningham, Brysson, D.Sc., B.E., M.Inst.C.E., Lecturer in Waterways, Harbours, and Docks, University College, London. 141 Copers Cope Road, Beckenham, Kent	
1930		* Cunningham, John, C.I.E., B.A., M.D., Lt.-Colonel, I.M.S. (retired). South Bank, Grange Loan, Edinburgh 10	
1934		* Daly, Ivan de Burgh, M.A., M.D., B.Ch., Professor of Physiology, University of Edinburgh (Teviot Place). Cooliney, Spylaw Avenue, Edinburgh	
1885		Daniell, Alfred, M.A., LL.B., D.Sc., Advocate, The Athenæum Club, London	
1934		* Darling, Frank Fraser, Ph.D. (Edin.), N.D.A., Dundonnell, by Garve, Wester Ross	
1924		* Darwin, Charles Galton, M.A., F.R.S. (VICE-PRESIDENT). Tait Professor of Natural Philosophy, University of Edinburgh (Drummond Street). 4 Churchhill, Edinburgh 10	1925–28. Sec. 1928–33. V-P 1933–
1932		* Davidson, Leybourne Stanley Patrick, B.A. (Cantab.), M.D. (Edin.), F.R.C.P.E., Regius Professor of Medicine, University of Aberdeen. 55 Queen's Road, Aberdeen	
1930	C.	* Davies, Lewis Merson, M.A., F.G.S., F.R.A.I., Lt.-Colonel, Royal Artillery (retired). 8 Garscube Terrace, Murrayfield, Edinburgh 12	
1931		* Dawson, Shepherd, M.A., D.Sc., Principal Lecturer in Psychology, Training College, Glasgow. Hazel Bank, Bearsden, Dumbartonshire	
1928		Dawson, Warren Royal, F.R.S.L., F.S.A.Scot., Honorary Librarian of Lloyd's. 28 Grange Road, Barnes, London, S.W. 13	
1917		* Day, T. Cuthbert, F.C.S., 36 Hillside Crescent, Edinburgh 7	
1923		* Deane, Arthur, M.R.I.A., Curator, Public Art Gallery and Museum, Belfast. Threave, 57 Cranmore Park, Belfast	
1894		† Denny, Sir Archibald, Bart., LL.D., 5 St Helen's Place, London, E.C. 4	
1925		Dey, Alexander John, Managing Director of T. & H. Smith, Ltd., Manufacturing Chemists, Edinburgh. Rothiemay, Corstorphine, Edinburgh 12	
1924		* Dinham, C. H., B.A., H.M. Geological Survey. Edgemoor, 19 Highfield Road, Northwood, Middlesex	
1885	C.	Dixon, James Main, M.A., Litt. Hum. Doctor, Professor of English, University of Southern California. University Avenue, Los Angeles, California, U.S.A.	
1923		* Dixon, Ronald Audley Martineau, of Thearne, F.G.S., F.S.A.Scot., F.R.G.S., Thearne Hall, near Beverley	
1881	C.	Dobbin, Leonard, Ph.D. (CURATOR OF LIBRARY AND MUSEUM), formerly Reader in Chemistry, University of Edinburgh. Faladam, Blackshiels, Midlothian	1904–07, 1913–16. Curator 1934–
1918		* Dodd, Alexander Scott, Ph.D., F.I.C., F.C.S., City Analyst for Edinburgh. 20 Stafford Street, Edinburgh 3	
1925		* Donald, Alexander Graham, M.A., F.F.A., F.S.A.Scot., Secretary of the Scottish Provident Institution, Edinburgh. 18 Carlton Terrace, Edinburgh 7	
1905		Donaldson, Rev. Wm. Galloway, J.P., F.R.G.S., F.E.I.S., The Manse of Forfar, Forfar	
1882	C.	Dott, David B., F.I.C., Memb. Pharm. Soc., Ravenslea, Musselburgh	
1921	M-B. C.	* Dougall, John, M.A., D.Sc., 47 Airthrey Avenue, Glasgow, W. 4	
1901 & 1918		Douglas, Carstairs Cumming, M.D., D.Sc., Professor of Medical Jurisprudence and Hygiene, Anderson's College, Glasgow. 110 South Brae Drive, Jordanhill, Glasgow	

Date of Election			Service on Council, etc.
1910		Douglas, Loudon MacQueen, Newpark, Mid-Calder, Midlothian	
1934		* Dow, David Rutherford, M.D., D.P.H., F.R.C.P.E., Professor of Anatomy, University of St Andrews (University College, Dundee). 16 Windsor Street, Dundee	
1932		* Drennan, Alexander Murray, M.D. (Edin.), F.R.C.P.E., Professor of Pathology, University of Edinburgh (Teviot Place)	
1923	C.	* Drever, James, M.A., B.Sc., D.Phil., Professor of Psychology, University of Edinburgh (South Bridge). Ivybank, Wardie Road, Edinburgh 5	1929–32.
1901		Drinkwater, Thomas W., L.R.C.P.E., L.R.C.S.E., Chemical Laboratory, Surgeons' Hall, Edinburgh	
1923		* Drummond, J. Montagu F., M.A. (Cantab.), Harrison Professor of Botany, University of Manchester	1928–31.
1925		* Dryerre, Henry, M.R.C.S., Ph.D., Professor of Physiology, Royal (Dick) Veterinary College; Physiological Biochemist, Animal Diseases Research Association. Kenmore, Lasswade	
1921		* Drysdale, Charles Vickery, C.B., O.B.E., D.Sc. (Lond.), M.I.E.E., F.Inst.P., formerly Director of Scientific Research to the Admiralty. Derek Corner, Kingsway, Hove, Sussex	
1904		Dunlop, William Brown, M.A., 4A St Andrew Square, Edinburgh 2. Seton Castle, Longniddry, E. Lothian	
1892	C.	Dunstan, Malcolm James Rowley, M.A., F.I.C., F.C.S., formerly Principal, Royal Agricultural College, Cirencester. Windyacres, Wrotham, Kent	
1933		* Dymond, Edmund Gilbert, M.A., Lecturer in Natural Philosophy, University of Edinburgh (Drummond Street). 8 Cobden Crescent, Edinburgh 9	
1906	C.	Dyson, Sir Frank Watson, K.B.E., M.A., D.Sc., LL.D., F.R.S., formerly Astronomer Royal, Royal Observatory, Greenwich. 27 Westcombe Park Road, Blackheath, S.E. 3	
1925		* Eastwood, George Samuel, B.Sc., Principal Teacher of Mathematics, Beath Secondary School, Cowdenbeath, Fife. Craigie Lea, Cowdenbeath, Fife	
1934		* Edge, William Leonard, M.A. (Cantab.), Lecturer in Mathematics, University of Edinburgh (16 Chambers Street)	
1904		Edwards, John, LL.D., 4 Great Western Terrace, Kelvinside, Glasgow	
1931		* Eggleton, Philip, D.Sc., Lecturer in Biochemistry, Department of Physiology, University of Edinburgh (Teviot Place). 36 Gillespie Crescent, Edinburgh 10	
1924		* Elliot, Rt. Hon. Walter Elliot, P.C., M.C., M.B., Ch.B., D.Sc., LL.D., M.P., Minister of Agriculture, 14 Markham Square, Chelsea, London	
1906	C.	Ellis, David, D.Sc., Professor of Botany and Bacteriology, Royal Technical College, Glasgow	
1933		* Erskine, John Maxwell, General Manager of the Commercial Bank of Scotland, Ltd. 10 Spylaw Road, Edinburgh 10	
1934		* Etherington, Ivor Malcolm Haddon, B.A. (Oxon.), Ph.D. (Edin.), Lecturer in Mathematics, University of Edinburgh (16 Chambers Street). 41 Scotland Street, Edinburgh 3	
1924		* Evans, Arthur Humble, M.A., Sc.D., Lecturer in English History. Cheviot House, Crowthorne, Berks	
1924		Evans, William Edgar, B.Sc., Assistant in charge of Herbarium, Royal Botanic Garden, Edinburgh 4	
1902		Ewen, John Taylor, O.B.E., B.Sc., M.I.Mech.E., J.P., H.M. Inspector of Schools (Emeritus), Pitscandly, Forfar	
1878	C.	† Ewing, Sir James Alfred, K.C.B., M.A., D.Sc., LL.D., F.R.S., Hon. Memb. Inst.C.E., formerly Principal, University of Edinburgh, and Director of Naval Education, Admiralty. 5 Herschel Road, Cambridge	1888–91, 1919–20. V-P 1920–23. P 1924–29.
1900	C.	Eyre, John W. H., M.D., M.S. (Dunelm), D.P.H. (Cantab.), formerly Professor of Bacteriology, Guy's Hospital. 51 Portland Place, London, W. 1	
1931		* Fairbairn, William Ronald Dodds, M.A., M.D., D.Psych.(Edin.), Lecturer in Psychology, University of Edinburgh (South Bridge). 18 Lansdowne Crescent, Edinburgh 12	
1910	C.	Fairgrieve, Mungo M'Callum, M.A. (Cantab. and Glas.), Senior Science Master, Edinburgh Academy. 37 Queen's Crescent, Edinburgh 9	

Date of Election			Service on Council, etc.
1907	C.	Falconer, John Downie, M.A., D.Sc., F.G.S., formerly Director of the Geological Survey of Nigeria. The Cedars, Hatton Road, Harlington, Hayes, Middlesex	
1923		* Feldman, William Moses, M.D., B.S., M.R.C.P., M.R.C.S., F.R.A.S., Senior Physician, St Mary's Hospital for Women and Children, Plaistow. 851 Finchley Road, London, N.W. 11	
1928		* Fenton, Edward Wyllie, M.A., B.Sc. (Aberd.), Head of Botany Department, Edinburgh and East of Scotland College of Agriculture, 13 George Square, Edinburgh 8	
1907		Fergus, Edward Oswald, c/o Messrs M'Kay & Boyd, Solicitors, 50 Wellington Street, Glasgow	
1933		* Ferguson, Thomas, M.D., D.P.H. (Edin.), F.R.C.P.E., D.Sc., Medical Officer, Department of Health for Scotland 4 Park Street, Falkirk	
1925	C.	* Ferrar, William Leonard, M.A., Fellow and Tutor of Hertford College, Oxford	
1932		* Findlay, Sir John Edmund Ritchie, Bart., B.A. (Oxon.), Proprietor of the *Scotsman*. 18 Lauder Road, Edinburgh 9	
1927	C.	* Finlay, Thomas Matthew, M.A., D.Sc. (Edin.), Lecturer in Palæontology, University of Edinburgh. 11 Dudley Terrace, Leith 6	
1911		† Fleming, John Arnold, F.C.S., Pottery Manufacturer, Locksley, Helensburgh, Dumbartonshire	
1906		Fleming, Robert Alexander, M.A., M.D., LL.D., F.R.C.P.E., Consulting Physician, Royal Infirmary. 10 Chester Street, Edinburgh 3	
1900	C. N.	Flett, Sir John S., K.B.E., M.A., D.Sc., LL.D., F.R.S., Director of the Geological Survey and Museum, Exhibition Road, South Kensington, London, S.W. 7	1916-19.
1872		Forbes, George, M.A., LL.D., F.R.S., M.Inst.C.E., M.Inst.E.E., F.R.A.S., formerly Professor of Natural Philosophy, Anderson's College, Glasgow. 11 Little College Street, Westminster, S.W.	
1892		Ford, John Simpson, F.I.C., 7 Corrennie Drive, Edinburgh 10	
1921		* Forrest, George Topham, F.R.I.B.A., F.G.S., Architect to the London County Council, County Hall, Westminster Bridge, London, S.E. 1	
1928	C.	* Forrest, James, M.A., B.Sc. (Glas.), D.Sc. (St Andrews), Lecturer in Physics, University College, Dundee. "Cumbrae," Oxford Street, Blackness, Dundee	
1933		* Forrester, Charles, A.H.-W.C., F.I.C., F.Inst.P., Vice-Principal and Professor of Chemistry, Indian School of Mines, Dhanbad, India	
1920	C.	* Franklin, Thomas Bedford, B.A. (Cantab.), 28 Kingshill Drive, Kenton, Middlesex	
1910		Fraser, Alexander, Actuary, 15 S. Learmonth Gardens, Edinburgh 4	
1929		* Fraser, David Kennedy, M.A., B.Sc., Psychologist to Glasgow Education Authority. Edge o' the Moor, Milngavie, Dumbartonshire	
1934		* Fraser, George, Chartered Civil Engineer, M.Inst.C.E., M.I.Struct.E. 25 Murrayfield Gardens, Edinburgh 12	
1928		* Fraser, John, M.C., M.D., Ch.M., F.R.C.S.E., Regius Professor of Clinical Surgery, University of Edinburgh (Royal Infirmary). 20 Moray Place, Edinburgh 3	
1928		* Fraser, Kenneth, M.D. (Edin.), D.P.H. (Cantab.), D.T.M. (Edin.), County Medical Officer of Health, Cumberland. The Croft, Scotby, near Carlisle	
1914		* Fraser, William, Managing Director, Neill & Co., Ltd., Printers, 212 Causewayside, Edinburgh 9	
1896	C.	Fraser-Harris, David Fraser, B.Sc. (Lond.), D.Sc. (Birm.), M.D., formerly Professor of Physiology, Dalhousie University, Halifax, Nova Scotia. Grove Park Lodge (3), Chiswick, London, W. 4	
1907		Galbraith, Alexander, "Ravenswood," Dalmuir, Glasgow	
1933		* Galbraith, Augustus William de Rohan, M.Inst.C.E., M.Inst.C.E.I., F.S.E., City Engineer, Christchurch, New Zealand. The Spur, Sumner, New Zealand	
1888	C.	Galt, Alexander, D.Sc., formerly Keeper of the Department of Technology, Royal Scottish Museum, Edinburgh. C/o Clydesdale Bank, 1 Melville Place, Edinburgh 3	
1901		Ganguli, Sanjiban, M.A., Principal, Maharaja's College, and Director of Public Instruction, Jaipur State, Jaipur, India	
1933		* Gardner, Alfred Charles, M.Inst.C.E., M.Inst.Mech.E., M.Inst.E.E., F.G.S., Chief Engineer, Clyde Navigation Trust, 16 Robertson Street, Glasgow. 324 Albert Drive, Pollokshields, Glasgow	

Date of Election			Service on Council, etc.
1926		* Gardner, John Davidson, B.Sc., A.M.Inst.C.E., Chief Assistant to Messrs D. & C. Stevenson, Civil Engineers, Edinburgh. 23 Ivy Terrace, Edinburgh 11	
1930	C.	* Geddes, Alexander Ebenezer M'Lean, O.B.E., M.A., D.Sc., Lecturer in Natural Philosophy, University of Aberdeen. 12 Louisville Avenue, Aberdeen	
1909	C.	† Geddes, Rt. Hon. Sir Auckland C., P.C., G.C.M.G., K.C.B., M.D., LL.D. Frensham, The Layne, Rolvenden, Kent	
1909		† Gentle, William, B.Sc., Head Master, George Heriot's School. 10 West Savile Road, Edinburgh 9	
1920	C.	* Ghosh, Sudhamoy, M.Sc. (Cal.), D.Sc. (Edin.), F.C.S., Professor of Chemistry, School of Tropical Medicine and Hygiene, Central Avenue, Calcutta, India	
1914		* Gibb, Sir Alexander, G.B.E., C.B., M.Inst.C.E., Queen Anne's Lodge, Westminster, London, S.W. 1	
1916		* Gibb, Alfred William, M.A., D.Sc., Professor of Geology, University of Aberdeen. 1 Belvidere Street, Aberdeen	
1910	C.	Gibb, David, M.A., B.Sc., Reader in Mathematics, University of Edinburgh (16 Chambers Street). 15 South Lauder Road, Edinburgh 9	
1917	C.	* Gibson, Alexander, M.B., Ch.B., F.R.C.S., 620 Medical Arts Building, Winnipeg, Canada	
1921		* Gibson, Walcot, D.Sc., F.R.S., F.G.S., formerly Assistant Director, H.M. Geological Survey (Scotland). Pathways, Fairlight Road, Hythe, Kent	
1911		Gidney, Sir Henry A. J., Kt., M.L.A., J.P., F.R.C.S.E., Lt.-Col., I.M.S. (retired), c/o The Allahabad Bank, Ltd., Calcutta, India	
1933		* Gillespie, Robert Pollock, M.A., B.Sc., Ph.D. (Cantab.), Lecturer in Mathematics, University of Glasgow. Ashcot, Kilbarchan Road, Johnstone, Renfrewshire	
1933		* Gillespie, Thomas Haining, Director-Secretary, Zoological Society of Scotland. Corstorphine Hill House, Murrayfield, Edinburgh 12	
1925		* Gillies, William King, M.A., B.A., F.E.I.S., LL.D. (Glas.), Rector of the Royal High School, Edinburgh. Davaar, 12 Suffolk Road, Edinburgh 9	
1907		Gilruth, John Anderson, M.R.C.V.S., D.V.Sc. (Melb.), Clowes Street, South Yarra, Melbourne, Australia	
1909		Gladstone, Hugh Steuart, M.A., M.B.O.U., F.Z.S., Capenoch, Penpoint, Dumfries	
1911		Gladstone, Reginald John, M.D., F.R.C.S., Lecturer and Senior Demonstrator of Anatomy, King's College, University of London. 22 Court Lane Gardens, London, S.E. 21	
1934		* Glaister, John, M.D., D.Sc. (Glas.), Professor of Forensic Medicine, University of Glasgow. 5 Kew Terrace, Glasgow, W. 2	
1925	C.	* Goldie, Archibald Hayman Robertson, M.A., B.A., Superintendent, Meteorological Office, Air Ministry, Edinburgh, 6 Drumsheugh Gardens, Edinburgh 3	1929–32.
1910		Goodall, Joseph Strickland, M.B. (Lond.), M.R.C.P., F.R.C.S.E., M.S.A. (Eng.), Professor of Physiology and Biology, City of London Hospital. 136 Harley Street, London, W. 1	
1901		Goodwillie, James, M.A., B.Sc., 239 Clifton Road, Aberdeen	
1913	C. M-B.	* Gordon, William Thomas, M.A., D.Sc. (Edin.), M.A. (Cantab.), Professor of Geology, University of London, King's College, Strand, W.C.	
1897		Gordon-Munn, John Gordon, M.D., Croys, Dalbeattie	
1934		* Gorrie, Robert Maclagan, D.Sc. (Edin.), Forest Research Institute, Dehra Dun, U.P., India	
1923		* Grabham, George Walter, O.B.E., M.A. (Cantab.), F.G.S., Government Geologist, Anglo-Egyptian Sudan. Box 178, Khartoum	
1924		Graham, Robert James Douglas, M.A., D.Sc., Professor of Botany, University of St Andrews	
1931		* Grant, Robert, Publisher (Oliver & Boyd), Edinburgh. 6 Kilgraston Road, Edinburgh 10	
1898	C.	Gray, Albert A., M.D., 5 Hammersmith Terrace, London, W. 6	
1909	C.	Gray, James Gordon, D.Sc., Professor of Applied Physics, University of Glasgow. 11 The University, Glasgow	1913–15.
1918		* Gray, William Forbes, F.S.A.Scot., 8 Mansionhouse Road, Edinburgh 9	
1927	C. K.	* Greenwood, Alan William, D.Sc. (Melb.), Ph.D. (Edin.), Lecturer in the Institute of Animal Genetics, University of Edinburgh (West Mains Road)	

Date of Election			Service on Council, etc.
1922		* Greenwood, William Osborne, M.D. (Leeds), B.S. (Lond.), L.S.A., Clerk in Holy Orders, Woodroyd, 19 Ripon Road, Harrogate, Yorks	
1925		* Greig, David Middleton, M.B., C.M., F.R.C.S.E., LL.D., Conservator of the Museum of the Royal College of Surgeons of Edinburgh. 12 Abbotsford Crescent, Edinburgh 10	
1906		Greig, Edward David Wilson, C.I.E., M.D., D.Sc., Lt.-Col., I.M.S. (retired), 38 Coates Gardens, Edinburgh 12	
1931		* Greig, John Russell, Ph.D. (Edin.), Director, Moredun Institute, Animal Diseases Research Association. Wedderlie, Kirkbrae, Liberton 9	
1905		† Greig, Sir Robert Blyth, M.C., LL.D., formerly Secretary to the Department of Agriculture for Scotland. The Shaws, Barnton, Midlothian	1921–24. V-P. 1924–27.
1910		Grimshaw, Percy Hall, I.S.O., F.R.E.S., Keeper, Natural History Department, Royal Scottish Museum. 49 Lygon Road, Edinburgh 9	
1899		† Guest, Edward Graham, M.A., B.Sc., J.P., 5 Newbattle Terrace, Edinburgh 10	
1927		* Gulland, John Masson, M.A. (Oxon.), D.Sc. (Edin.), Ph.D. (St Andrews), Reader in Biochemistry, University of London, Lister Institute, Chelsea Bridge Road, London, S.W. 1	
1907		Gulliver, Gilbert Henry, D.Sc., A.M.I.Mech.E., 99 Southwark Street, London, S.E.	
1930		* Guthrie, Douglas, M.D., F.R.C.S., Lecturer in Diseases of the Ear, Nose, and Throat, School of Medicine of the Royal Colleges, Edinburgh. 4 Rothesay Place, Edinburgh 3	
1933	C.	* Guthrie, William Gilmour, M.A. (Edin.), B.A. (Cantab.), Ph.D., Professor of Mathematics and Natural Philosophy, Magee College, Londonderry, Northern Ireland	
1911		* Guy, William, F.R.C.S., L.R.C.P., L.D.S.Ed., LL.D. (Penn.), Consulting Dental Surgeon, Edinburgh Royal Infirmary; Lecturer on Human and Comparative Dental Anatomy and Physiology. 11 Wemyss Place, Edinburgh 3	
1934		* Haldane, David, B.Sc. (Edin.), Senior Geologist, H.M. Geological Survey (Scotland), 19 Grange Terrace, Edinburgh 9. 6 Kilmaurs Road, Edinburgh 9	
1922		* Hannay, Robert Kerr, M.A., LL.D., H.R.S.A., Fraser Professor of Scottish History and Palæography, University of Edinburgh (South Bridge). Historiographer-Royal for Scotland. 5 Royal Terrace, Edinburgh 7	
1923		* Hanneford-Smith, William, A.M.Inst.C.E., Hon. A.R.I.B.A. 1 The Avenue, Gravesend, Kent	
1918		* Hardie, Patrick Sinclair, M.A., B.Sc., formerly Head of the Physics Department, Medical School, Cairo. 10 Baldovan Road, Downfield, Dundee	
1928		* Harding, William Gerald, F.R.Hist.S., F.S.A.Scot., F.R.E.S., Peckwater House, Charing, Kent	
1923	C.	* Harris, Robert Graham, M.A., D.Sc. (Edin.), Lorraine, Manor Road, Farnborough, Hants	
1914		Harrison, Edward Philip, Ph.D., F.Inst.P., Chief Scientist, H.M.S. "Vernon," Portsmouth	
1934		* Harrison, John Vernon, D.Sc. (Glas.), F.G.S., 34 Rowallan Gardens, Glasgow, W. 1	
1921		* Harrison, John William Heslop, D.Sc. (Durham), F.R.S., Professor of Botany, Armstrong College, Newcastle. The Avenue, Birtley, Co. Durham	
1926	C.	* Harrower, John Gordon, M.B., Ch.M. (Glas.), F.R.C.S.E., D.Sc., (Edin.), Professor of Anatomy, King Edward VII Medical College, and Surgeon, General Hospital, Singapore	
1926		* Harvey, William Frederick, C.I.E., M.A., M.B., C.M., D.P.H., Lieut.-Col., I.M.S. (retired), Histologist, Research Laboratory, Royal College of Physicians, Edinburgh. 56 Garscube Terrace, Edinburgh 12	
1893		Hehir, Sir Patrick, K.C.I.E., C.B., C.M.G., F.R.C.P.E., F.R.C.S.E., D.P.H., (Cantab.), D.T.M. (Liverpool), Maj.-General, I.M.S. (retired). 12 Lansdowne Place, Hove, Sussex	
1931		* Henderson, John, F.C.I.I., Manager and Secretary, Edinburgh Assurance Co. Ltd. Seaforth Cottage, York Road, Trinity, Edinburgh 5	
1929		* Henderson, Thomas, C.B.E., J.P., F.S.A.Scot., Actuary of the Savings Bank of Glasgow. 5 Belmont Crescent, Glasgow, W. 2	
1908		Henderson, William Dawson, M.A., B.Sc., Ph.D., Lecturer, Zoological Laboratories, University, Bristol. 77 Coldharbour Road, Bristol 6	

Date of Election			Service on Council, etc.
1925		* Heron, Alexander Macmillan, D.Sc., Superintendent, Geological Survey of India, Calcutta, India	
1916		* Herring, Percy Theodore, M.D., F.R.C.P.E. (VICE-PRESIDENT), Professor of Physiology, University of St Andrews. Linton, St Andrews	1917–20, 1931–34. V-P 1934–
1922		Hindle, Edward, M.A., Sc.D. (Cantab.), Ph.D., A.R.C.S., London School of Hygiene and Tropical Medicine. 1 Ormonde Gate, Chelsea, London, S.W. 3	
1902		Hinxman, Lionel W., B.A., formerly of the Geological Survey of Scotland. 4 Morant Gardens, Ringwood, Hants	
1904		Hobday, Sir Frederick T. G., Kt., C.M.G., Dr. Med. Vet. (Zurich), F.R.C.V.S., Principal, Royal Veterinary College, Camden Town, London, N.W. 1	
1928	C.	* Hobson, Alfred Dennis, M.A. (Cantab.), Professor of Zoology, Armstrong College, Newcastle-upon-Tyne	
1928		* Hodge, William Vallance Douglas, M.A. (Edin.), M.A. (Cantab.), University Lecturer. 8 Grange Gardens, Grange Road, Cambridge	
1885		Hodgkinson, William Richard, C.B.E., M.A., Ph.D., F.I.C., F.C.S., formerly Professor of Chemistry and Metallurgy, Artillery College, Woolwich. 89 Shooters Hill Road, Blackheath, Kent	
1923	C.	* Hogben, Lancelot Thomas, M.A., D.Sc., Professor of Social Biology (London School of Economics), University of London, Houghton Street, W.C. 2	
1927		Holden, Henry Smith, D.Sc., F.L.S., Professor of Botany, University College, Nottingham	
1930		* Holland, Sir Thomas Henry, K.C.S.I., K.C.I.E., D.L., Hon. D.Sc., LL.D., F.R.S. (VICE-PRESIDENT), Vice-Chancellor and Principal of the University of Edinburgh. Blackford Brae, Edinburgh 9	1931–32. V-P 1932–
1929	C.	* Hora, Sunder Lal, D.Sc. (Punjab et Edin.), F.L.S., F.Z.S., F.A.S.B., Senior Assistant Superintendent, Zoological Survey of India. Indian Museum, Calcutta	
1920	C.	* Horne, Alexander Robert, O.B.E., B.Sc., M.I.Mech.E., A.M.Inst.C.E., Professor of Mechanical Engineering, Heriot-Watt College, Edinburgh. 31 Queen's Crescent, Edinburgh 9	
1896		Horne, J. Fletcher, M.D., F.R.C.S.E., Shelley Hall, Huddersfield	
1904	C.	Horsburgh, Ellice Martin, M.A., D.Sc., Reader in Technical Mathematics, University of Edinburgh (16 Chambers Street). 11 Granville Terrace, Edinburgh 10	
1912	C. M-B.	* Houstoun, Robert Alexander, M.A., Ph.D., D.Sc., Lecturer in Physical Optics, University of Glasgow. 45 Kirklee Road, Glasgow	1929–32.
1893		Howden, Robert, M.A., M.B., C.M., D.Sc., LL.D., Emeritus Professor of Anatomy, University of Durham. Broomfield, Crieff	
1933		* Hume, Edgar Erskine, D.S.M., B.A., M.A., LL.D., Lieut.-Col., U.S. Army, Librarian of the Army Medical Library, Washington. The Magnolias, Frankfort, Kentucky	
1910		Hume, William Fraser, D.Sc. (Lond.), Director, Geological Survey of Egypt, Helwân, Egypt. The Laurels, Rustington, Sussex	
1927		* Hunt, Owen Duke, B.Sc. (Manch.), "Corrofell," Newton Ferrers, South Devon	
1923		* Hunter, Rev. Adam Mitchell, M.A., D.Litt., Librarian of New College, Edinburgh. 3 Suffolk Road, Edinburgh 9	
1932		* Hunter, Andrew, M.A., B.Sc., M.D., F.R.S.C., Professor of Biochemistry, University of Glasgow	
1928		* Hunter, Arthur, F.F.A., LL.D. (Edin.), Vice-President and Chief Actuary of the New York Life Insurance Co. 124 Lloyd Road, Montclair, N.J., U.S.A.	
1916		* Hunter, Charles Stewart, L.R.C.P.E., L.R.C.S.E., D.P.H., Cotswold, 36 Streatham Hill, London, S.W. 2	
1911		Hunter, Gilbert Macintyre, M.Inst.C.E., M.Inst.E.S., M.Inst.M.E. Auchraig, Cramond Brig, near Edinburgh	
1887	C.	Hunter, William, C.B., M.D., M.R.C.P.L. and E., M.R.C.S., LL.D., 103 Harley Street, London	
1927		* Hyslop, James, M.A. (Glas.), Ph.D. (Cantab.), Lecturer in Mathematics, University of Glasgow. Criffel View, Rotchell Park, Dumfries	
1923	C.	* Ince, Edward Lindsay, M.A. (Cantab.), D.Sc. (Edin.), Lecturer in Mathematics, Imperial College of Science and Technology, South Kensington. 6 Rutland Gardens, West Ealing, London, W. 13	

Date of Election			Service on Council, etc.
1920		* Inglis, James Gall, Publisher. 36 Blacket Place, Edinburgh 9	
1927		* Inglis, John Alexander, of Auchindinny and Redhall, K.C., M.A. (Oxon.), LL.B. (Edin.), King's and Lord Treasurer's Remembrancer. 13 Randolph Crescent, Edinburgh 3	
1912		* Inglis, Robert John Mathieson, M.Inst.C.E., Assistant Chief Engineer, L.N.E.R., Liverpool Street Station, London. Dixton, Hadley Common, Barnet	
1917		* Irvine, Sir James Colquhoun, Kt., C.B.E., Ph.D. (Leipzig), D.Sc. (St Andrews), Hon. D.Sc. (Liverpool, Princeton), Hon. Sc.D. (Cantab., Yale, Pennsylvania), Hon. LL.D. (Glas., Aberd., Edin., and Toronto), Hon. D.C.L. (Durham), D.L., F.R.S., Hon. F.E.I.S., Hon. Mem. American Chemical Society, Vice-Chancellor and Principal of the University of St Andrews	1920–22. V-P 1922–25.
1930	C.	* Jack, David, M.A., B.Sc. (Edin.), Ph.D. (St Andrews), Lecturer in Natural Philosophy, United College, University of St Andrews. 22 Grange Road, St Andrews	
1923		* Jack, John Louttit, Solicitor, Assistant Secretary, Department of Health for Scotland, 121A Princes Street, Edinburgh 2	
1912	C.	* Jeffrey, George Rutherford, M.D. (Glas.), F.R.C.P. (Edin.), Bootham Park Private Mental Hospital, York	
1934		* Jeffrey, Sir John, K.C.B., C.B.E., Under-Secretary of State for Scotland. 9 Cluny Gardens, Edinburgh 10	
1906	C. K.	Jehu, Thomas John, M.A., M.D., F.G.S., Professor of Geology, University of Edinburgh (Grant Institute of Geology, West Mains Road). 35 Great King Street, Edinburgh 3	1917–20, 1923–26. V-P 1929–32.
1900		† Jerdan, David Smiles, M.A., D.Sc., Ph.D., 26 Avenue du Château d'Eau, Saventhem, Belgium	
1931		* Johnson, Thomas, D.Sc. (Lond.), Emeritus Professor of Botany, Royal College of Science for Ireland. Tomeg, Hillview Drive, Corstorphine 12	
1895		Johnston, Col. Henry Halcro, C.B., C.B.E., D.Sc., M.D., C.M. (Edin.), F.L.S., late Administrative Staff, Army. Stromness Hotel, Stromness, Orkney	
1934		* Johnston, Sir William Campbell, W.S., LL.D., J.P., Deputy Keeper of the Signet. 43 Castle Street, Edinburgh 2	
1928		* Johnston-Saint, Percy Johnston, M.A. (Cantab.), Secretary, Wellcome Historical Medical Museum, 183 Euston Road, London, N.W. 1. 4 Wyndham Place, Bryanston Square, London, W. 1	
1928		* Johnstone, Robert William, C.B.E., M.A., M.D. (Edin.), F.R.C.S.E., M.R.C.P.E., Professor of Midwifery and Diseases of Women, University of Edinburgh. 26 Palmerston Place, Edinburgh 12	
1927		* Jones, Edward Taylor, D.Sc. (Lond.), Professor of Natural Philosophy, University of Glasgow	1927–30.
1930	C.	* Jones, Samuel Griffith, D.Sc. (Univ. Wales), Lecturer in Botany, University of Glasgow. Broomfield, Kilmacolm, Renfrewshire	
1928	C.	* Jones, Tudor Jenkyn, M.B., Ch.B. (Glas.), Lecturer in Anatomy, University of Liverpool	
1922		* Juritz, Charles Frederick, M.A., D.Sc., F.I.C., Chief of the Union Department of Chemistry. Villa Marina, Three Anchor Bay, Cape Town, South Africa	
1925	C.	* Kemp, Charles Norman, B.Sc., Technical Radiologist, Secretary of the Royal Scottish Society of Arts. Ivy Lodge, Laverockbank Road, Edinburgh 5	
1929		* Kendall, James Pickering, M.A., D.Sc., F.R.S. (SECRETARY TO ORDINARY MEETINGS), Professor of Chemistry, University of Edinburgh (West Mains Road). 14 Mayfield Gardens, Edinburgh 9	1931–33. Sec. 1933–
1912		† Kennedy, Robert Foster, M.D. (Belfast), M.B., B.Ch. (R.U.I.), Associate Professor of Neurology, Cornell University, New York. 410 East 57th Street, New York, U.S.A.	
1927		* Kennedy, Walter Phillips, Ph.D. (Edin.), L.R.C.P. and S.E., A.I.C., Professor of Biology, British Medical College, Baghdad	
1909		Kenwood, Henry Richard, C.M.G., M.B., C.M., Emeritus Chadwick Professor of Hygiene, University of London. "Wadhurst," Queen's Road, Finsbury Park, London, N.	
1925	C. M-B.	* Kermack, William Ogilvy, M.A., D.Sc., Chemist, Research Laboratory of the Royal College of Physicians, 2 Forrest Road, Edinburgh 1	

Date of Election			Service on Council, etc.
1903 & 1923	C. N.	Kerr, John Graham, M.A., F.R.S., F.L.S., F.Z.S., Regius Professor of Zoology, University of Glasgow. 9 The University, Glasgow	1904–07, 1913–16, 1924–27. V.-P 1928–31.
1891		Kerr, Joshua Law, M.D., J.P., "Stonehaven," Sheffield, Tasmania	
1913		* Kerr, Walter Hume, M.A., B.Sc., formerly Lecturer in Engineering Drawing and Structural Design, University of Edinburgh. Glenfriars, Jedburgh	
1926		* Khastgir, Satis Ranjan, M.Sc. (Calcutta), D.Sc. (Edin.), Physics Department, University, Dacca, India	
1907		King, Archibald, M.A., B.Sc., H.M. Inspector of Schools, 10 Leslie Road, Pollokshields, Glasgow	
1925		* King, Leonard Augustus Lucas, M.A., Professor of Zoology, West of Scotland Agricultural College, Glasgow. 14 Bank Street, Glasgow, W. 2	
1918		* Kingon, Rev. John Robert Lewis, M.A., D.Sc., The Manse, Dundee, Natal Province, South Africa	
1901		Knight, Rev. G. A. Frank, M.A., D.D., F.S.A.Scot., 10 Hillhead Street, Glasgow	
1907		Knight, James, M.A., D.Sc., F.C.S., F.G.S., J.P., Rector, Queen's Park High School, Langside, Glasgow	
1927		* Lambie, Charles George, M.C., M.D., F.R.C.P.E., Bosch Professor of Medicine, University of Sydney, Australia	
1920	C.	* Lamont, John Charles, Lieut.-Col., I.M.S. (retired), C.I.E., M.B., C.M. (Edin.), M.R.C.S., 7 Merchiston Park, Edinburgh 10	
1925	C. N.	* Lang, William Henry, M.B., C.M., D.Sc., LL.D. (Glas.), F.R.S., Barker Professor of Cryptogamic Botany, University of Manchester	
1931		* Langrishe, John du Plessis, D.S.O., M.B., B.Ch. (Dub.), D.P.H., Lt.-Col. R.A.M.C. (retired), Lecturer in Public Health, University of Edinburgh (Usher Institute of Public Health, Warrender Park Road). 2 South Gillsland Road, Edinburgh 10	
1910	C.	Lauder, Alexander, D.Sc., Head of Chemistry Department, Edinburgh and East of Scotland College of Agriculture, 13 George Square, Edinburgh 8. Lecturer in Agricultural Chemistry, University of Edinburgh	1917–20. Sec. 1923–28.
1885	C.	Laurie, Arthur Pillans, M.A., D.Sc., LL.D., formerly Principal, Heriot-Watt College, Edinburgh. 38 Springfield Road, St John's Wood, London, N.W. 8	1908–11, 1913–16.
1921		* Laurie, The Rev. Albert Ernest, M.C., C.F., D.D., Rector of Old St Paul's, and Canon of St Mary's Cathedral, Edinburgh. Lauder House, Jeffrey Street, Edinburgh 1	
1905		Lawson, David, M.A., M.D., L.R.C.P. and S.E., Druimdarroch, Banchory, Kincardineshire	
1903		Leighton, Gerald Rowley, O.B.E., M.D., D.Sc., formerly Medical Officer (Foods), Department of Health for Scotland. Sharston, near Ramsey, Isle of Man	
1930		* Lelean, Percy Samuel, C.B., C.M.G., F.R.C.S., L.R.C.P., D.P.H., Professor of Public Health, University of Edinburgh (Usher Institute of Public Health, Warrender Park Road). 2 Barnton Loan, Davidson's Mains, Edinburgh 4	
1910		Levie, Alexander, F.R.C.V.S., D.V.S.M., Balmae, Manor Road, Littleover, Derby	
1916	C.	* Levy, Hyman, M.A., D.Sc., Professor of Mathematics, Imperial College of Science and Technology, London. Kitelands, Micheldever Station, Hants	
1914	C. N.	Lewis, Francis John, D.Sc., F.L.S., Professor of Botany, University of Alberta, Edmonton, Alberta, Canada	
1918		* Lidstone, George James, F.F.A., F.I.A., LL.D., formerly Manager and Actuary, Scottish Widows' Fund Life Assurance Society. Hermiston House, Hermiston, Currie, Midlothian	1919–22.
1905		Lightbody, Forrest Hay, 53 Queen Street, Edinburgh 2	
1931		* Lightfoot, Nicholas Morpeth Hutchinson, M.A. (Cantab.), Lecturer in Mathematics, Heriot-Watt College, Edinburgh. 3 Park Gardens, Liberton, Edinburgh 9	
1923		* Lim, Robert Kho Seng, M.B., Ch.B., D.Sc., Peking Union Medical College, Department of Physiology, Peking, China	
1912		* Lindsay, John George, M.A., B.Sc. (Edin.), Rector of Dunfermline High School	

Date of Election			Service on Council, etc.
1920	C.	* Lindsay, Thomas A., M.A., B.Sc., Head Master, Higher Grade School, Bucksburn, Aberdeenshire	
1912		* Linlithgow, The Most Honourable the Marquis of, K.T., G.C.I.E., D.L. (VICE-PRESIDENT), Hopetoun House, South Queensferry	V-P 1934–
1903		† Liston, William Glen, C.I.E., M.D., Lt.-Col., I.M.S. (retired), Milburn Tower, Gogar, Corstorphine, Edinburgh 12	
1929		* Little, John Robert, F.C.I.I., F.C.I.S., formerly Manager and Secretary, Century Insurance Co., Ltd. 5 Dalrymple Crescent, Edinburgh 9	
1932		* Lockhart, James Balfour, M.A., B.Sc. (Edin.), Mathematical Master, Edinburgh Academy. Dundas House, Kinnear Road, Edinburgh 4	
1926		* Lorraine, Norman Stanley Rees, M.D., D.P.H. (Edin. and Glas.), Medical Officer of Health, Shoeburyness Urban District. 1 Burlescoombe Leas, Burlescoombe Road, Thorpe Bay, Southend-on-Sea	
1930		* Low, James Wotherspoon, B.Sc. (Edin.), Ph.D. (Bristol), 14 Great Stuart Street, Edinburgh 3	
1934		* Low, R. Cranston, M.D., F.R.C.P.E., formerly Lecturer in Dermatology, University of Edinburgh. 1 Randolph Crescent, Edinburgh 3	
1923	C.	* Ludlam, Ernest Bowman, M.A., D.Sc., Lecturer in Chemistry, University of Edinburgh (West Mains Road)	
1923		* Lyford-Pike, James, M.A., B.Sc., Lecturer in Forestry, University of Edinburgh. Rosetta, Liberton, Edinburgh 9	
1924		* Lyon, David Murray, M.D., F.R.C.P.E., D.P.H., D.Sc., Professor of Therapeutics and Clinical Medicine, University of Edinburgh (Royal Infirmary). Druim, Colinton, Edinburgh 11	
1894		Mabbott, Walter John, M.A., formerly Rector of County High School, Duns, Berwickshire. The Hawthorn, Farnham Lane, Haslemere, Surrey	
1929		* M'Arthur, Donald Neil, D.Sc., F.I.C., Professor of Agricultural Chemistry, West of Scotland Agricultural College, Glasgow, C. 2. 35 Kersland Street, Glasgow, W. 2	
1921		* M'Arthur, Neil, M.A., B.Sc., Lecturer in Mathematics, University of Glasgow. 1 Holyrood Crescent, Glasgow	
1926		* M'Bride, James Alexander, B.A. (Roy. Univ., Ireland), B.Sc. (Lond.), formerly Rector of Queen's Park Secondary School, Glasgow. Scottish Liberal Club, Princes Street, Edinburgh 2	
1883		M'Bride, Peter, M.D., F.R.C.P.E., 3 St Peter's Grove, York	
1931	C.	* McCallien, William John, D.Sc. (Glas.), Lecturer in Geology, University of Glasgow. Glenorchy, Tarbert, Argyll	
1930		* M'Candlish, Andrew Corrie, B.Sc. (Glas.), M.S.A., Ph.D. (Iowa), Advisory Officer in Milk Production, West of Scotland Agricultural College. St Quivox Road, Prestwick, Ayrshire	
1923		* M'Cracken, William, J.P., F.S.I., Englesea House, Crewe	
1931	C.	* M'Crea, William Hunter, M.A., Ph.D. (Cantab.), B.Sc. (Lond.), F.R.A.S., Asst. Professor of Mathematics, University of London. Imperial College of Science and Technology, South Kensington, S.W. 7	
1918		* M'Culloch, Rev. James David, 3 Ardgowan Street, Greenock	
1905		Macdonald, Hector Munro, O.B.E., M.A., LL.D., F.R.S., Professor of Mathematics, University of Aberdeen. 52 College Bounds, Aberdeen	1908–11.
1897	C.	Macdonald, James A., M.A., B.Sc., formerly H.M. Inspector of Schools. "Rothes," Frankscroft, Peebles	
1920		* M'Donald, Stuart, M.A., M.D., F.R.C.P.E., Professor of Pathology, University of Durham. College of Medicine, Newcastle-on-Tyne	
1928		* MacDonald, Thomas Logie, M.A., B.Sc. (Glas.), F.R.A.S., 9 Colebrooke Terrace, Glasgow, W. 2	
1904		Macdonald, William, M.S.Agr., Sc.D., D.Sc., Editor, *Agricultural Journal* of South Africa. Rand Club, Johannesburg, Transvaal	
1886		Macdonald, William J., M.A., LL.D., 15 Comiston Drive, Edinburgh 10	
1931		* M'Dougall, John Bowes, M.D. (Glas.), F.R.F.P.S.G., F.R.C.P.E., Medical Director, British Legion Village, Preston Hall, Kent. Preston Hall, Aylesford, Kent	
1901	C.	MacDougall, R. Stewart, M.A., D.Sc., LL.D. (Edin.), Emeritus Professor of Biology, Royal (Dick) Veterinary College, Edinburgh. Ivy Lodge, Gullane, East Lothian	1914–17.
1910		Macewen, Hugh Allen, O.B.E., M.B., Ch.B., D.P.H. (Lond. and Cantab.), Local Government Board, Ministry of Health, Whitehall, London, S.W.	

Date of Election			Service on Council, etc.
1888	C.	M'Fadyean, Sir John, Kt., M.B., B.Sc., LL.D., formerly Principal and Professor of Comparative Pathology, Royal Veterinary College, Camden Town, London. Highlands House, Leatherhead	
1885	C.	† Macfarlane, J. M., D.Sc., LL.D., Emeritus Professor of Botany. 427 West Hansberry Street, Germantown, Pa., U.S.A.	
1897		MacGillivray, Angus, M.D., C.M., D.Sc., 23 South Tay Street, Dundee	
1878		M'Gowan, George, F.I.C., Ph.D., 21 Montpelier Road, Ealing, London, W. 5	
1932		* MacGregor, Archibald Gordon, M.C., B.Sc., Geologist, H.M. Geological Survey (Scotland). 1 Greenbank Terrace, Edinburgh 10	
1922		* Macgregor, Murray, M.A., D.Sc., Assistant Director (Scotland), H.M. Geological Survey. 19 Grange Terrace, Edinburgh 9	1930–33.
1903		M'Intosh, Donald C., M.A., D.Sc., formerly Education Officer, Elgin. Tomlay, Tomintoul, Banffshire	
1911		M'Intosh, John William, M.R.C.V.S., Dollis Hill Farm, Cricklewood, London, N.W. 2	
1927	C.	* M'Intyre, Donald, M.B.E., M.D. (Glas.), F.R.C.S.E., Assistant Physician, Glasgow Royal Maternity and Women's Hospital. 9 Park Circus, Glasgow, C. 3	
1912	C.	M'Kendrick, Anderson Gray, M.B., D.Sc., F.R.C.P.E., Lt.-Col., I.M.S. (retired), Superintendent, Research Laboratory, Royal College of Physicians, 2 Forrest Road, Edinburgh 1	1924–27. 1933–
1914		* M'Kendrick, Archibald, F.R.C.S.E., D.P.H., L.D.S., J.P., 12 Rothesay Place, Edinburgh 3	
1900	C.	M'Kendrick, John Soutar, M.D., F.R.F.P.S. (Glas.), 2 Buckingham Terrace, Hillhead, Glasgow	
1910	C.	Mackenzie, Alister, M.A., M.D., D.P.H., Principal Medical Officer and Lecturer in Hygiene, Training Centre, Jordanhill, Glasgow. 22 Queen's Gate, Dowanhill, Glasgow	
1916	C.	* Mackenzie, John E., D.Sc., Reader in Chemistry, University of Edinburgh (West Mains Road). 2 Ramsay Garden, Edinburgh 1	
1905		Mackenzie, Sir William Colin, K.B., M.D., F.R.C.S., Director, Australian Institute of Anatomy, Canberra, F.C.T., Australia	
1904	C.	Mackenzie, Sir W. Leslie, M.A., M.D., D.P.H., LL.D., F.R.C.P.E., formerly Medical Member of the Scottish Board of Health. 14 Belgrave Place, Edinburgh 4	
1929	C.	* Mackie, John, M.A., D.Sc., Rector, Leith Academy. 19 Beresford Avenue, Trinity, Leith 5	
1928		* Mackie, Thomas Jones, M.D., M.R.C.P.E., Professor of Bacteriology, University of Edinburgh (Teviot Place). 22 Mortonhall Road, Edinburgh 9	
1910		MacKinnon, James, M.A., Ph.D., LL.D., Emeritus Professor of Ecclesiastical History, University of Edinburgh. 12 Lygon Road, Edinburgh 9	1933–
1904		Mackintosh, Donald James, C.B., M.V.O., D.L., M.B., C.M., LL.D., Superintendent, Western Infirmary, Glasgow	
1899		Maclean, Sir Ewan John, M.D., D.Sc. (Hon.), LL.D., F.R.C.P. (Lond.), D.L., J.P., Emeritus Professor of Obstetrics and Gynæcology, Welsh National Medical School. 12 Park Place, Cardiff	
1888	C.	Maclean, Magnus, M.A., D.Sc., LL.D., M.Inst.C.E., M.I.E.E., formerly Professor of Electrical Engineering, Royal Technical College. 108 University Avenue, Glasgow, W. 2	1916–19.
1933		* Macleod, James, F.I.C., Manager, Glasgow Corporation Chemical Works Department. 16 Colebrooke Street, Glasgow, W. 2	
1932		* Macleod, John James Rickard, M.B., Ch.B. (Aberd.), D.Sc. (Toronto), LL.D., F.R.S., Professor of Physiology, University of Aberdeen	
1916	C.	* M'Lintock, William Francis Porter, D.Sc. (Edin.), Geological Survey and Museum, Exhibition Road, South Kensington, London, S.W. 7	
1923		* Macmillan, Rt. Hon. Lord, P.C., LL.D., 44 Millbank, Westminster, S.W. 1	
1932		* M'Neil, Charles, M.A., M.D. (Edin.), F.R.C.P.E., Professor of Child Life and Health, University of Edinburgh (Royal Edinburgh Hospital for Sick Children). 44 Heriot Row, Edinburgh 3	
1917		* Macpherson, Rev. Hector Copland, M.A., Ph.D., F.R.A.S., Guthrie Memorial U.F. Church. 7 Wardie Crescent, Edinburgh 5	
1921		* M'Quistan, Dougald Black, M.A., B.Sc., Associate-Professor of Natural Philosophy, Royal Technical College, Glasgow. 29 Viewpark Drive, Rutherglen	

Date of Election			Service on Council, etc.
1921	C.	* MacRobert, Thomas Murray, M.A., D.Sc., Professor of Mathematics, University of Glasgow. 10 The University, Glasgow	1931–34.
1921	C.	* M'Whan, John, M.A. (Glasgow), Ph.D. (Gött.), Lecturer in Mathematics, University of Glasgow. 84 Munro Road, Jordanhill, Glasgow, W. 3	
1927		* Madwar, Mohamed Reda, Ph.D. (Edin.), A.M.Inst.C.E., Director, Helwân Observatory, Egypt	
1898	C.	† Mahâlanobis, S. C., B.Sc. (Edin.), Professor of Physiology, University of Calcutta. P. 45 New Park Street, Calcutta	
1913		Majumdar, Tarak Nath, D.P.H. (Cal.), L.M.S., F.C.S., Health Officer, IV, Calcutta. P. 235 Russa Road, P.O. Tollygunge	
1933		* Malcolm, John, M.D. (Edin.), Professor of Physiology, University of Dunedin, New Zealand, Medical School, King Street, Dunedin	
1917		* Malcolm, L. W. Gordon, M.Sc. (Cantab.), Ph.D., F.L.S., Conservator, Wellcome Historical Medical Museum, 183 Euston Road, London, N.W. 1	
1908		Mallik, Devendranath, Sc.D., B.A., Principal, Carmichael College, Rungpur, Bengal, India	
1912		† Maloney, William Joseph, M.B.E., M.C., M.D. (Edin.), LL.D., formerly Professor of Neurology, Fordham University. Casa del Sale, Newport, Rhode Island, N.Y., U.S.A.	
1913		Marchant, Rev. Sir James, K.B.E., LL.D., F.R.A.S., F.L.S., Director, National Council for Promotion of Race-Regeneration. Pinegarth, Buccleuch Road, Bournemouth	
1901	C.	Marshall, Francis Hugh Adam, C.B.E., Sc.D., F.R.S., Reader in Agricultural Physiology, University of Cambridge. Christ's College, Cambridge	
1920	C.	* Marshall, John, M.A., D.Sc. (St Andrews), B.A. (Cantab.), University Reader in Mathematics, Bedford College, London. Logan House, 123 Torrington Park, London, N. 12	
1931		* Mason, John Huxley, F.R.C.V.S., Government Veterinary Laboratory, Onderstepoort, Pretoria, South Africa	
1885	C.	Masson, Sir David Orme, K.B.E., M.A., D.Sc., LL.D., F.R.S., Emeritus Professor of Chemistry, University of Melbourne	
1913		Masson, George Henry, M.D., D.Sc., F.R.C.P.E., Port of Spain, Trinidad, British West Indies	
1898	C. M-B.	Masterman, Arthur Thomas, M.A., D.Sc., F.R.S., formerly Superintending Inspector, H.M. Board of Agriculture and Fisheries. 3 Kedale Road, Seaford	1902–04.
1911		† Mathews, Gregory Macalister, M.B.O.U., Meadway, St Cross, Winchester, Hants	
1921		* Mathieson, John, F.R.S.G.S., Division Superintendent, Ordnance Survey (retired), 42 East Claremont Street, Edinburgh 7	
1906		Mathieson, Robert, F.C.S., St Serf's, Innerleithen	
1928		* Matthai, George, M.A. (Cantab.), F.Z.S., F.L.S., Professor of Zoology, Government College, Lahore, India	
1924		* Matthews, James Robert, M.A., F.L.S., Professor of Botany, University of Aberdeen	
1932		* Maxwell, William, Managing Director of R. & R. Clark, Ltd. 14 South Inverleith Avenue, Edinburgh 4	
1917		* Maylard, A. Ernest, M.B., B.Sc. (Lond.), F.R.F.P.S. (Glasgow), Kingsmuir, Peebles	
1922		* Meakins, Jonathan Campbell, M.D., LL.D., F.R.C.P.E., Professor of Medicine and Director of the Department of Medicine, McGill University, Montreal, Canada	
1931		* Mears, Frank Charles, F.R.I.B.A., 3 Forres Street, Edinburgh 3	
1901	C.	Menzies, Alan W. C., M.A., Ph.D., F.C.S., Professor of Chemistry, Princeton University, Princeton, New Jersey, U.S.A.	
1927		* Menzies, Sir Frederick Norton Kay, K.B.E., M.D., LL.D. (Edin.), F.R.C.P.E., D.P.H. (Lond.), Medical Officer of Health and School Medical Officer, Administrative County of London, County Hall, London, S.E.	
1933	C.	* Menzies, William John Milne, Inspector of Salmon Fisheries of Scotland, Fishery Board *for* Scotland. Tighbeag, Whitehouse Road, Cramond Bridge, near Edinburgh	
1929		* Mercer, Walter, M.B., Ch.B., F.R.C.S.E., Lecturer in Clinical Surgery, University of Edinburgh (Royal Infirmary). 12 Rothesay Terrace, Edinburgh 3	

Date of Election			Service on Council, etc.
1917		* Merson, George Fowlie, Manufacturing Technical Chemist, St John's Hill Works, Edinburgh 8	
1902	C.	† Metzler, William H., A.B., D.Sc., Ph.D., formerly Dean of the New York State College for Teachers, Albany, N.Y., U.S.A. 4 Glenwood Street, Albany, N.Y., U.S.A.	
1885	C. M-B.	Mill, Hugh Robert, D.Sc., LL.D., Hill Crest, Dormans Park, E. Grinstead	
1910		Miller, John, M.A., D.Sc., Professor of Mathematics, Royal Technical College. 212 Wilton Street, Glasgow, N.W.	
1930		* Miller, William Christopher, M.R.C.V.S., Courtauld Professor of Animal Husbandry, Royal Veterinary College, Camden Town, London, N.W. 1	
1905		Milne, Archibald, M.A., D.Sc., Deputy Director of Studies, Edinburgh Provincial Training College. 38 Morningside Grove, Edinburgh 10	
1905		Milne, C. H., M.A., D.Litt., Head Master, Daniel Stewart's College. 19 Merchiston Gardens, Edinburgh 10	
1904	C.	Milne, James Robert, D.Sc., Lecturer in Natural Philosophy, University of Edinburgh (Drummond Street). 7 Grosvenor Crescent, Edinburgh 12	
1886		Milne, William, M.A., B.Sc., 70 Beechgrove Terrace, Aberdeen	
1933	C.	Milne-Thomson, Louis Melville, M.A. (Cantab.), F.R.A.S., Professor of Mathematics, Royal Naval College, Greenwich. Gothic House, Maze Hill, London, S.E. 10	
1899		Milroy, Thomas Hugh, M.D., B.Sc., LL.D., Professor of Physiology, Queen's University, Belfast	
1889	C. K.	Mitchell, A. Crichton, D.Sc., Hon. Doc. Sc. (Genève), formerly Director of Public Instruction in Travancore, India. 246 Ferry Road, Edinburgh 5. (Society's Representative on Governing Body of Heriot-Watt College)	1915–16, 1930–33. Cur. 1916–26. V-P 1926–29.
1897		† Mitchell, George Arthur, M.A., 9 Lowther Terrace, Kelvinside, Glasgow	
1900		Mitchell, James, M.A., B.Sc., Islay Lodge, Lochgilphead, Argyll	
1911		Modi, Edalji Manekji, D.Sc., LL.D., Litt.D., F.C.S., Arthur Road Chemical Works, Meher Buildings, Tardeo, Bombay, India	
1906		† Moffat. Rev. Alexander, M.A., LL.D., formerly Professor of Physics, Christian College, Madras. C/o National Bank of India, Post Box No. 64, Madras, India	
1929		Moir, Henry, F.F.A., F.I.A., President, United States Life Insurance Co., 156 Fifth Avenue, New York City. Upper Montclair, New Jersey	
1890	C.	† Mond, Sir Robert Ludwig, Kt., M.A. (Cantab.), LL.D., F.C.S., 9 Cavendish Square, London, W. 1	
1887	C.	Moos, N. A. F., D.Sc., J.P., Director of Bombay and Alibag Observatories (retired). Red Leaf, Pedder Road, Bombay, India	
1896		Morgan, Alexander, O.B.E., M.A., D.Sc., formerly Principal, Edinburgh Provincial Training College. 1 Midmar Gardens, Edinburgh 10	
1930		* Morison, John Miller Woodburn, M.D., F.R.C.P.E., D.M.R. and E., Professor of Radiology, University of London, and Director of the Radiological Department, Cancer Hospital, Fulham Road, London, S.W. 3	
1926		* Morris, James Archibald, R.S.A., F.S.A.Scot., Savoy Croft, Ayr	
1919		* Morris, Robert Owen, O.B.E., M.A., M.D., C.M. (Edin.), D.P.H. (Liverpool). King Edward VII Welsh National Memorial Association (Tuberculosis). Hafod-ar-For, Aberdovey, N. Wales	
1892	C.	Morrison, J. T., M.A., D.Sc., Emeritus Professor of Mathematical Physics, University, Stellenbosch, South Africa	
1930		* Morton, James, LL.D., Governing Director, Scottish Dyes, Ltd. Tuethur, Carlisle	
1901		Moses, O. St John, M.D., D.Sc., F.R.C.S., Lt.-Col., I.M.S. (retired), formerly Professor of Medical Jurisprudence, Medical College, Calcutta. 18 Manstone Road, Cricklewood, London, N.W. 2	
1892	C. K.	Mossman, Robert Cockburn, Lacar 4332, Villa Devoto F.C.P., Buenos Aires, Argentina	
1934		* Mowat, Magnus, C.B.E., M.Inst.C.E., M.I.Mech.E., Brigadier-General, Secretary of the Institution of Mechanical Engineers, Storey's Gate, London, S.W. 1	

Date of Election			Service on Council, etc.
1916		* Muir, Sir Robert, Kt., M.A., M.D., Sc.D., LL.D., F.R.S., F.R.C.P.E., Professor of Pathology, University of Glasgow. 30 Victoria Crescent Road, Glasgow, W. 2	
1907		Muirhead, James M. P., J.P., F.R.S.L., F.S.S., "Carmel," Rouwkoop Road, Rondebosch, South Africa	
1933		* Murray, John, M.A. (Aberd.), Ph.D. (Edin.), Rector, The Academy, Annan. 9 Seaforth Avenue, Annan	
1932		* Murray, John Murdoch, B.Sc. (Edin.), Assistant Commissioner for Scotland, Forestry Commission. 76 Hillview Terrace, Corstorphine, Edinburgh 12	
1934		* Murray, Walter George Robertson, A.I.C., Technical Assistant, Department of Chemistry, University of Edinburgh (West Mains Road). 20 Montpelier Park, Edinburgh 10	
1907		† Musgrove, James, M.D., F.R.C.S., F.R.C.S.E., LL.D., Emeritus Professor of Anatomy, University of St Andrews. The Swallowgate, St Andrews	
1931		* Nelson, Alexander, B.Sc. (Glas.), Ph.D. (Edin.), N.D.A., Lecturer in Plant Physiology and Agricultural Botany, University of Edinburgh. 11 Wardie Avenue, Edinburgh 5	
1924		* Nelson, Philip, M.A., M.D., Ph.D., F.S.A., Beechwood, Calderstones, Liverpool	
1898		Newman, Sir George, K.C.B., M.D., D.C.L., LL.D., F.R.C.P., Chief Medical Officer, Ministry of Health and Board of Education, Whitehall, London, S.W. 1	
1928		* Nichols, James Edward, M.Sc. (Dunelm), Ph.D. (Edin.), Wool Industries Research Association, Torridon, Headingley, Leeds. Moorfield Cottage, Arthington, Yorks	
1933	C.	* Nicol, Thomas, M.B., Ch.B., F.R.C.S.E., D.Sc., Lecturer in Anatomy, University of Glasgow. 77 Fotheringay Road, Glasgow, S. 1	
1927		* Noble, Thomas Paterson, M.D. (Edin.), F.R.C.S., Phya Thai Palace, Bangkok, Siam	
1934	C.	* Normand, Alexander Robert, M.A., B.Sc., Ph.D. (Edin.), formerly Professor of Chemistry, Wilson College, Bombay. 7 India Street, Edinburgh 3	
1928	C. N.	* O'Donoghue, Charles Henry, D.Sc. (Lond.), Reader in Zoology, University of Edinburgh (West Mains Road). Appin Lodge, Eskbank, Midlothian	
1925		* Ogg, William Gammie, M.A., Ph.D., Director, Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen; Research Lecturer in Soil Science in the University of Aberdeen	
1923	C.	* Ogilvie, Alan G., O.B.E., M.A., B.Sc. (Oxon.), Professor of Geography, University of Edinburgh (High School Yards). 40 Fountainhall Road, Edinburgh 9	1932–
1929		* Ogilvie, Frederick Wolff, M.A., Vice-Chancellor and President of Queen's University, Belfast	
1886		Oliver, James, M.D., F.L.S., Physician to the London Hospital for Women, 123 Harley Street, London, W.	
1895	C.	† Oliver, Sir Thomas, Kt., D.L., M.D., LL.D., F.R.C.P., ex-Vice Chancellor of the University of Durham. 7 Ellison Place, Newcastle-upon-Tyne	
1930		* Oliver, William, B.Sc., A.M.Inst.C.E., Professor of Organisation of Industry and Commerce, University of Edinburgh (South Bridge). 70 Netherby Road, Trinity, Edinburgh 5	
1930		* O'Riordan, George Francis, B.Sc. (Eng.), M.I.Mech.E., Principal of Battersea Polytechnic, London, S.W. 7. Hesslewood, 3 Hazlewell Road, Putney, London, S.W. 15	
1924		* Orr, John Boyd, D.S.O., M.C., M.A., D.Sc., M.D., F.R.S., Director of the Rowett Research Institute for Research in Animal Nutrition, Aberdeen	
1915		* Orr, Lewis P., F.F.A., formerly General Manager of the Scottish Life Assurance Co., 3 Belgrave Place, Edinburgh 4	
1932		* Orr, Matthew Young, 38 Lennox Row, Edinburgh 5	
1927		* Owen, William John, Memb. Roy. Soc. Victoria, Director, Department of Histology, Australian Institute of Anatomy, Canberra, Australia	
1908		Page, William Davidge, 13 Yarrell Mansions, Queen's Club Gardens, London, W. 14	
1934		* Pal, Rudrendra Kumar, D.Sc. (Edin.), M.R.C.P.E., L.R.C.S.E., Professor of Physiology, Prince of Wales Medical College, Patna, India	
1905		Pallin, Lt.-Col. William Alfred, C.B.E., D.S.O., F.R.C.V.S., 5 Tower Gardens, Hythe, Kent	
1924		* Parker, Joseph, D.Sc., Principal, Fife Mining School, Cowdenbeath. 128 Stenhouse Street, Cowdenbeath	

Date of Election			Service on Council, etc.
1933		Parsons, Charles Wynford, B.A., Lecturer in Zoology, University of Glasgow. Westbank, 65 Partickhill Road, Glasgow	
1901		Paterson, David, F.C.S., Leewood, Rosslyn Castle, Midlothian	
1918		* Paterson, Rev. William Paterson, D.D., LL.D., Emeritus Professor of Divinity, University of Edinburgh (South Bridge). 39 George Square, Edinburgh 8	
1927		* Patterson, Charles, A.M.I.Mar.E., Lecturer in Mechanical Engineering Design, University of Edinburgh (Sanderson Engineering Laboratories, Mayfield Road). 22 Dudley Terrace, Trinity, Edinburgh 6	
1926		* Patton, Donald, M.A., Ph.D., Lecturer in Botany, Glasgow Provincial College for the Training of Teachers. 15 Jordanhill Drive, Glasgow, W. 3	
1923	C.	* Peacock, Alexander David, D.Sc., Professor of Zoology, University College, Dundee	
1907		Pearce, John Thomson, B.A., B.Sc., Bolton Manse, Haddington, East Lothian	
1914		Pearson, Joseph, D.Sc., F.L.S., formerly Director of the Colombo Museum, and Marine Biologist to the Ceylon Government. Director of the Tasmanian Museum, Hobart, Tasmania	
1904		Peck, James Wallace, C.B., M.A., Second Secretary, Scottish Education Department, Dover House, Whitehall, London, S.W. 1	1926–28.
1887	C. M-B.	Peddie, William, D.Sc., Professor of Natural Philosophy, University College, Dundee. The Weisha, Ninewells, Dundee	1904–07, 1908–11, 1933– V-P 1919–22.
1925		* Penman, David, D.Sc., M.Inst.M.E., Principal, Indian School of Mines, Dhanbad, India	
1893		Perkin, Arthur George, Hon. D.Sc. (Leeds), F.R.S., F.I.C., Emeritus Professor in the University of Leeds. Grosvenor Lodge, Grosvenor Road, Headingley, Leeds	
1931	C.	* Phemister, James, M.A., D.Sc. (Glas.), Senior Geologist, H.M. Geological Survey (Scotland). Everland, 2 Denham Green Terrace, Edinburgh 5	
1889		† Philip, Sir Robert William, Kt., M.A., M.D., LL.D., F.R.C.P.E., Professor of Tuberculosis, University of Edinburgh. 45 Charlotte Square, Edinburgh 2	V-P 1927–30.
1907	C.	† Phillips, Charles E. S., O.B.E., Castle House, Shooters Hill, Woolwich, S.E. 18	
1929	C.	* Phillips, John Frederick Vicars, D.Sc., F.L.S., Professor of Botany, University of the Witwatersrand, Johannesburg, Union of South Africa	
1932		* Pickard, James Nichol, B.A. (Cantab.), Ph.D. (Edin.), Little Craufurd, Lasswade, Midlothian	
1928		* Pilcher, Robert Stuart, General Manager, Manchester Corporation Tramways. 55 Piccadilly, Manchester	
1914		* Pilkington, Basil Alexander, "Kambla," Davidson's Mains, Edinburgh 4	
1933		* Pillers, Alfred William Noel, F.R.C.V.S., D.V.S.M., Chief Veterinary Officer to the Corporation of the City of Liverpool; Lecturer in Veterinary Parasitology, University of Liverpool. Hawkstone, Queen's Drive, Walton, Liverpool 4	
1908	C.	† Pirie, James Hunter Harvey, B.Sc., M.D., F.R.C.P.E., Research Pathologist and Bacteriologist, South African Institute for Medical Research. P.O. Box 1038, Johannesburg, South Africa	
1911		* Pirie, James Simpson, M.Inst.C.E., 25 Grange Road, Edinburgh 9	
1906		Pitchford, Herbert Watkins, C.M.G., F.R.C.V.S., Victoria Club, Pietermaritzburg, South Africa	
1934		* Plenderleith, Harold James, M.C., B.Sc., Ph.D. (St Andrews), F.C.S., Assistant Keeper, 1st Class, in Research Laboratory of British Museum, London. 134 The Vale, Golder's Green, N.W. 11	
1924		* Ponder, Eric, M.D., D.Sc., Professor of General Physiology, Washington Square College, New York University, New York, U.S.A.	
1919		* Porritt, B. D., M.Sc. (Lond.), F.I.C., Director of Research, Research Association of British Rubber Manufacturers, 105–7 Lansdowne Road, Croydon, Surrey	
1888		† Prain, Sir David, Kt., Lt.-Col., I.M.S. (retired), C.M.G., C.I.E., M.A., M.B., LL.D., F.R.S., F.L.S., For. Memb. K. Svensk. Vetensk. Akad.; Hon. Memb. Soc. Lett. ed Arti d. Zelanti, Acireale; Pharm. Soc. Gt. Britain; Corr. Memb. Bayer. Akad. Wiss., etc.; formerly Director, Royal Botanic Gardens, Kew, Surrey. The Well Farm, Warlingham, Surrey	

Date of Election			Service on Council, etc.
1932		* Prasad, Gorakh, D.Sc. (Edin.), Reader in Mathematics, University of Allahabad. Beli Road, Allahabad, India	
1926	C.	* Prashad, Baini, D.Sc., Superintendent, Zoological Survey of India, Indian Museum, Calcutta	
1933		* Preston, Frank Anderson Baillie, L.R.I.B.A., F.S.A.Scot., Lecturer in Municipal Engineering, Royal Technical College, Glasgow. 27 Ferguson Avenue, Milngavie	
1915		† Price, Frederick William, M.D. (Edin.), Consulting Physician to the Royal Northern Hospital, London ; Senior Physician to the National Hospital for Diseases of the Heart. 133 Harley Street, London, W.	
1932		* Price, Thomas Slater, O.B.E., D.Sc., F.R.S., Professor of Chemistry, Heriot-Watt College, Edinburgh. 2 Cluny Drive, Edinburgh 10	
1932		* Pringle, John, Hon. D.Sc., F.G.S., Palæontologist, Geological Survey of Great Britain, Exhibition Road, South Kensington, London, S.W. 7	
1911		Purdy, John Smith, D.S.O., M.D., C.M. (Aberd.), D.P.H. (Cantab.), F.R.G.S., Town Hall, Sydney, N.S.W., Australia	
1920	C.	* Purser, George Leslie, M.A. (Cantab.), F.Z.S., Lecturer in Embryology, University of Aberdeen	
1898		Purves, John Archibald, D.Sc., Chilliswood, Trull, Taunton	
1899	C.	Ramage, Alexander G., Lochcote, Linlithgowshire	
1904		Ratcliffe, Joseph Riley, M.B., C.M., c/o The Librarian, University, Birmingham	
1900		Raw, Nathan, C.M.G., M.D., 30 Clarendon Court, Maida Vale, London, W. 9	
1927	C.	* Read, Herbert Harold, D.Sc. (Lond.), A.R.C.S., F.G.S., George Herdman Professor of Geology, University of Liverpool	
1929		* Read, Selwyn, B.A., Schoolmaster, Edinburgh Academy. 2 Oxford Terrace, Edinburgh 4	
1902		Rees-Roberts, John Vernon, M.D., D.Sc., D.P.H., 90 Fitzjohns Avenue, Hampstead, London, N.W. 3	
1913		Reid, Harry Avery, O.B.E., F.R.C.V.S., D.V.H., Bacteriologist and Pathologist, Department of Agriculture, Wellington, New Zealand. C/o Bank of New Zealand, 1 Queen Victoria Street, London, E.C.	
1924		* Reid, William Carstairs, Civil Engineer, 23 Saxe-Coburg Place, Edinburgh 3	
1914		Renshaw, Graham, M.D., M.R.C.S., L.R.C.P., L.S.A., Editor of the *Avicultural Magazine*, Sale Bridge House, Sale, Manchester	
1913		* Richardson, Harry, M.Inst.E.E., M.Inst.M.E., 16 Stratford Place, London, W. 1	
1908		Richardson, Linsdall, F.G.S., 104 Greenfield Road, Harbourne, Birmingham	
1927		* Richey, James Ernest, B.A., B.A.I. (Trinity College, Dublin), Sc.D., F.G.S., District Geologist, H.M. Geological Survey (Scotland), 19 Grange Terrace, Edinburgh 9	
1930		* Ritchie, Allan Watt, Chief Sanitary Inspector, City of Edinburgh. 2 Queensferry Terrace, Edinburgh 4	
1916	C.	* Ritchie, James, M.A., D.Sc., Regius Professor of Natural History, University of Aberdeen	1921–24, 1926–28. Sec. 1928–31. V-P 1931–34.
1914	C.	* Ritchie, James Bonnyman, D.Sc., Rector, The Academy, Ayr. 28 Carrick Road, Ayr	
1906	C.	Ritchie, William Thomas, M.D., F.R.C.P.E., Professor of Medicine, University of Edinburgh (Teviot Place). 10 Douglas Crescent, Edinburgh 12	
1929		* Robb, Richard Alexander, M.A., B.Sc., M.Sc., Lecturer in Mathematics, University of Glasgow. 27 Moor Road, Eaglesham, Renfrewshire	
1931		* Robb, William, N.D.A., Director of Research, Scottish Society for Research in Plant Breeding. Craigs House, Corstorphine, Midlothian	
1898	C.	Roberts, Hon. Alexander William, D.Sc., F.R.A.S., Lovedale, South Africa	
1919		* Roberts, Alfred Henry, O.B.E., M.Inst.C.E., Superintendent and Engineer, Leith Docks. 40 Buckingham Terrace, Edinburgh 4	
1926		* Roberts, John Alexander Fraser, M.A. (Cantab.), D.Sc., Stoke Park Colony, Stapleton, Bristol	
1928	C.	* Roberts, Owen Fiennes Temple, M.C., M.A. (Cantab.), Lecturer in Astronomy and Meteorology, University of Aberdeen. 20 Belgrave Terrace, Aberdeen	
1902	C.	Robertson, Robert A., M.A., B.Sc., formerly Professor of Botany, University of St Andrews. White Gables, Allestree (Darley Abbey), Derbyshire	

Date of Election			Service on Council, etc.
1919		* Robertson, William Alexander, F.F.A., Century Insurance Co., Ltd., 18 Charlotte Square. Mardale, 3 Buckstone Park, Edinburgh 10	
1896	C.	Robertson, W. G. Aitchison, D.Sc., M.D., F.R.C.P.E., Barrister-at-Law, Lincoln's Inn. St Margarets, St Valerie Road, Bournemouth	
1932	C.	* Robson, John Michael, M.D., B.Sc., Beit Fellow, Institute of Animal Genetics, University of Edinburgh (West Mains Road). Tayinloan, Loanhead	
1926		* Romanis, William Hugh Cowie, M.A., M.B., M.C. (Cantab.), F.R.C.S., Surgeon to St Thomas's Hospital, London. 120 Harley Street, London, W. 1	
1916		* Ronald, David, M.Inst.C.E., Chief Engineer, Scottish Board of Health, 125 George Street, Edinburgh 2	
1909	C.	Ross, Alexander David, M.A., D.Sc., F.Inst.P., F.R.A.S., Professor of Physics, University of Western Australia, Perth, Western Australia	
1921		* Ross, Edward Burns, M.A., formerly Professor of Mathematics, Madras Christian College, Madras. 41 Liberton Brae, Edinburgh 9	
1931	C.	* Ruse, Harold Stanley, M.A. (Oxon.), D.Sc., Lecturer in Mathematics, University of Edinburgh (16 Chambers Street)	
1906		Russell, Alexander Durie, B.Sc., Mathematical Master, Falkirk High School. 14 Heugh Street, Falkirk	
1930		Russell, David, LL.D., Paper Manufacturer. Silverburn, Leven, Fife	
1902	C. K.	Russell, James, 22 Glenorchy Terrace, Edinburgh 9	
1934		* Rutherford, Daniel Edwin, M.A., B.Sc. (St Andrews), D.Math. (Amsterdam), Carnegie Teaching Fellow in Mathematics, United College, University of St Andrews. 8 Moredun Terrace, Perth	
1925	C.	* Saddler, William, M.A., B.A., Professor of Mathematics, Canterbury College, Christchurch, N.Z.	
1906		Saleeby, Caleb Williams, M.D., 13 Greville Place, Hampstead, London, N.W. 6	
1916	C.	* Salvesen, The Rt. Hon. Lord, P.C., K.C., LL.D., Judge of the Court of Session (retired), Dean Park House, Edinburgh 4	1920–22. V-P 1922–25.
1934		* Salvesen, Harold Keith, M.A. (Oxon. and Harvard), Captain (retired, I.A.), Shipowner, Inveralmond, Cramond, Midlothian	
1914		* Salvesen, Theodore Émile, of Culrain, F.R.S.A., F.S.A.Scot., Chevalier de la Légion d'Honneur. 37 Inverleith Place, Edinburgh 4	
1912	C. K.	* Sampson, Ralph Allen, M.A., D.Sc., LL.D., F.R.S. (Vice-President), Astronomer Royal for Scotland, Professor of Astronomy, University of Edinburgh. Royal Observatory, Edinburgh	1912–15, 1919–21. V-P 1915–18, 1933– Sec. 1922–23. Gen. Sec. 1923–33.
1903		Samuel, Sir John S., K.B.E., D.L., J.P., F.S.A.Scot., 13 Park Circus, Glasgow	
1927	C.	* Sandeman, Ian, M.A., B.Sc., Ph.D. (St Andrews), Acting Chief Inspector of Schools, Education Department, Colombo, Ceylon	
1930		* Sansome, Frederick Whalley, Ph.D., F.L.S., Assistant, John Innes Horticultural Institution, Merton, London. Old Garden, Church Lane, Merton Park	
1922		* Sarkar, Bijali Behari, M.Sc., D.Sc. (Edin.), Lecturer in Physiology, University, Calcutta. 33/3 Lansdowne Road, Calcutta	
1903		Sarolea, Charles, Ph.D., D.Litt., formerly Professor of French, University of Edinburgh. 21 Royal Terrace, Edinburgh 7	
1927	C.	* Schlapp, Robert, M.A. (Edin.), Ph.D. (Cantab.), Lecturer in Applied Mathematics, University of Edinburgh (16 Chambers Street). 1 Peel Terrace, Edinburgh 9	
1885	C.	† Scott, Alexander, M.A., D.Sc., F.R.S., Director of Scientific Research at the British Museum. 34 Upper Hamilton Terrace, London, N.W. 8	
1919		* Scott, Alexander, M.A., D.Sc., 3 Winton Terrace, Stoke-on-Trent	
1919		* Scott, Alexander Ritchie, B.Sc. (Edin.), D.Sc. (Lond.), Principal, London County Council, Beaufoy Institute, Prince's Road, London, S.E. 11	
1917		* Scott, Henry Harold, M.D., F.R.C.P., M.R.C.S., D.P.H., Assistant Director, Bureau of Hygiene and Tropical Diseases, Keppel Street, Gower Street, London, W.C. 1. 23 Gordon Mansions, London, W.C. 1	

Date of Election			Service on Council, etc.
1928		* Senior-White, Ronald, F.R.E.S., Malariologist, Bengal-Nagpur Railway, Kidderpore, P.O., Calcutta, India	
1930		* Shankland, Ernest Claud, F.R.Met.S., River Superintendent, Port of London Authority. Mariners, Balfour Gardens, Folkestone	
1900	C. N.	Sharpey-Schafer, Sir Edward Albert, Kt., M.D., D.Sc., LL.D., F.R.S. Corresponding Member of the French Academy of Medicine, Emeritus Professor of Physiology, University of Edinburgh. Park End, North Berwick	1900–03, 1906–09, 1918–19. V-P 1913–17. P 1929–34.
1927		* Sharpley, Forbes Wilmot, B.Sc. (Eng.) (Lond.), M.Inst.E.E., Professor of Electrical and Mechanical Engineering, Indian School of Mines, Dhanbad, India	
1931		* Shaw, John James M'Intosh, M.A., M.D., F.R.C.S., Lecturer in Surgery and Clinical Surgery, University of Edinburgh. Greenaway, Kinnear Road, Edinburgh 4	
1927		* Shearer, Ernest, M.A., B.Sc. (Edin.), Professor of Agriculture and Rural Economy, Edinburgh University, and Principal, Edinburgh and East of Scotland College of Agriculture, 13 George Square, Edinburgh 8	
1931		* Shearer, James Fleming, M.A., B.Sc., Ph.D., Lecturer in Natural Philosophy, University of Glasgow. 79 Queen's Drive, Wavertree, Liverpool 15	
1932		* Sheppard, William Fleetwood, Sc.D., LL.M., formerly a Senior Examiner to the Board of Education. Cardrona, Berkhamsted, Herts	
1932		* Simpson, Alexander Rudolf Barbour, B.Sc. (Edin.), M.A. (Cantab.), F.R.G.S., Senior Geography Master, Canford School. Beaufort House, Canford School, Wimborne, Dorset	
1908		Simpson, George Freeland Barbour, M.D., F.R.C.P.E., F.R.C.S.E., J.P., 43 Manor Place, Edinburgh 3	
1932	C.	* Simpson, John Baird, B.Sc. (Aberd.), Senior Geologist, H.M. Geological Survey (Scotland), 19 Grange Terrace, Edinburgh 9	
1900		Sinhjee, Sir Bhagvat, G.C.I.E., M.D., LL.D. (Edin.), H.H. the Thakur Sahib of Gondal, Kathiawar, Bombay, India	
1903		† Skinner, Robert Taylor, M.A., J.P., formerly House Governor, Donaldson's Hospital. 35 Campbell Road, Edinburgh 12	
1930	C.	* Slater, Robert Henry, D.Sc., Ph.D. (Edin.), Department of Chemical Pathology, St Mary's Hospital, London, W. 2	
1929		* Smail, James Cameron, A.Inst.E.E., Principal, Heriot-Watt College, Edinburgh. 1 Grange Terrace, Edinburgh 9	1934–
1926		* Small, James, D.Sc., Professor of Botany, Queen's University, Belfast. Orkla, 50 Myrtlefield Park, Belfast	
1901		Smart, Edward, B.A., B.Sc., Tillyloss, Tullylumb Terrace, Perth	
1920		* Smellie, William Robert, M.A., D.Sc., Geologist on the Staff of the Anglo-Persian Oil Company. Baron Cliff, Cove, Dumbartonshire	
1928		Smith, Alick Drummond Buchanan, M.A., B.Sc. (Agric.) (Aberd.), M.S.A. (Iowa), Lecturer, Institute of Animal Genetics, University of Edinburgh (West Mains Road)	
1921		* Smith, Norman Kemp, M.A., D.Phil., D.Litt., LL.D., Professor of Logic and Metaphysics, University of Edinburgh (South Bridge). Ellerton, Grange Loan, Edinburgh 9	
1923		* Smith, Percy James Lancelot, M.A. (Oxon.), F.I.C., F.C.S., Science Master, Loretto School. 47 Dalrymple Loan, Musselburgh	
1911		* Smith, Stephen, B.Sc., 34 Craigmillar Park, Edinburgh 9	
1929		* Smith, Sydney, M.D., F.R.C.P., D.P.H., Professor of Forensic Medicine, University of Edinburgh (Teviot Place). 10 Oswald Road, Edinburgh 9	
1907	C.	† Smith, William Ramsay, D.Sc., M.D., C.M., Permanent Head of the Health Department, South Australia. Belair, South Australia	
1919		* Smith, Sir William Wright, Kt., M.A., D. ès Sc., Regius Professor of Botany, University of Edinburgh, Regius Keeper of the Royal Botanic Garden, and King's Botanist in Scotland. Inverleith House, Edinburgh 4	Sec. 1923–28. V-P 1928–31.
1932		* Sneeden, Jean-Baptiste Octave, B.Sc., Ph.D. (Glas.), Lecturer on Heat Engines, Royal Technical College, Glasgow. 39 Kingshouse Avenue, Cathcart, Glasgow	

Date of Election			Service on Council, etc.
1899		Snell, Ernest Hugh, M.D., B.Sc., D.P.H. (Cantab.), Barrister-at-Law, late Medical Officer of Health, Coventry. 3 Eaton Road, Coventry	
1880		Sollas, William Johnson, M.A., D.Sc., LL.D., F.R.S., Professor of Geology and Palæontology, University of Oxford. 104 Banbury Road, Oxford	
1933		* Somerville, John Livingston, C.A., Auditor to the University of Edinburgh. Beechcroft, Ravelston Dykes, Edinburgh	
1929		* Southwell, Thomas, D.Sc., A.R.C.S., Lecturer in Parasitology, School of Tropical Medicine, Liverpool. 53 Greenhill Road, Mossley Hill, Liverpool 18	
1925		* Staig, Robert Arnot, M.A., Ph.D., Lecturer in Zoology, University of Glasgow. Glenlea, Lasswade, Midlothian	
1891		Stanfield, Richard, A.R.S.M., M.Inst.C.E., Emeritus Professor of Mechanics and Engineering, Heriot-Watt College, Edinburgh. 24 Mayfield Gardens, Edinburgh 9	1926–29.
1923		* Stebbing, Edward Percy, M.A., Professor of Forestry, University of Edinburgh (George Square)	
1885 & 1915		Steggall, John Edward Aloysius, M.A., Hon. A.R.I.B.A., LL.D., Emeritus Professor of Mathematics, University College, Dundee (St Andrews University). Woodend, Perth Road, Dundee	
1923		* Stenhouse, Andrew G., F.G.S., 191 Newhaven Road, Edinburgh 6	
1929	C.	* Stephen, Alexander Charles, D.Sc., Assistant, Natural History Department, Royal Scottish Museum, Edinburgh. "Eastcroft," Cramond Bridge, Edinburgh 4	
1910		Stephenson, Thomas, D.Sc., F.C.S., 13 Glencairn Crescent, Edinburgh 12	
1931		* Steven, George Alexander, B.Sc. (Edin.), Assistant Naturalist, Marine Laboratory, Plymouth. 1 Lipson Terrace, Plymouth, Devon	
1925		* Stevens, Alexander, M.A., B.Sc., Lecturer in Geography, University of Glasgow	
1886	C.	Stevenson, Charles A., B.Sc., M.Inst.C.E., Radella, North Berwick	
1884		† Stevenson, David Alan, B.Sc., M.Inst.C.E., Troqueer, Kingsknowe, Colinton, Midlothian	1928–31.
1919		* Stevenson, David Alan, B.Sc., M.Inst.C.E., 22 Glencairn Crescent, Edinburgh 12	
1931		* Stewart, Corbet Page, Ph.D. (Edin.), Lecturer in General Biochemistry, University of Edinburgh (Teviot Place). 17 Orchard Road South, Edinburgh 4	
1925		* Stewart, David Smith, Ph.D., M.Inst.C.E., Lecturer on Structural Engineering Drawing, University of Edinburgh (Sanderson Engineering Laboratories, Mayfield Road). 82 Lasswade Road, Liberton, Edinburgh 9	
1924		* Stiles, Sir Harold Jalland, K.B.E., M.B., F.R.C.S.E., LL.D., Emeritus Professor of Clinical Surgery, University of Edinburgh. Whatton Lodge, Gullane, E. Lothian	1934–
1902		Stockdale, Herbert Fitton, LL.D., formerly Director of the Royal Technical College, Glasgow. Clairinch, Upper Helensburgh, Dumbartonshire	
1889	C.	Stockman, Ralph, M.D., LL.D., F.R.C.P.E., F.F.P.S.G., Professor of Materia Medica and Therapeutics, University of Glasgow	1903–05.
1926		* Stokoe, William Norman, B.Sc., Ph.D. (Lond.), Chief Chemist, Craigmillar Creamery Co., Ltd. 8 Cobden Road, Edinburgh 9	
1906		Story, Fraser, O.B.E., formerly Professor of Forestry, University College, Bangor, North Wales. 4K Artillery Mansions, Victoria Street, London, S.W. 1	
1907		Strong, John, C.B.E., M.A., LL.D., Emeritus Professor of Education, University of Leeds. C/o The Librarian, The University, Leeds	
1930	C.	* Stump, Claude Witherington, M.D., D.Sc., Professor of Embryology and Histology, University of Sydney	
1903		Sutherland, David W., C.I.E., M.D., M.R.C.P., Lt.-Col., I.M.S. (retired), Braeside, Belhaven, Dunbar	
1930		* Sutherland, John Donald, C.B.E., LL.D., Commander of the Order of Leopold, Chevalier of the Legion of Honour, Forestry Commissioner, Scotland. 11 Inverleith Row, Edinburgh 4	
1925		Sutton, Richard L., M.D., D.Sc., LL.D., 1308 Bryant Building, 1102 Grand Avenue, Kansas City, Mo., U.S.A.	
1932		* Swinton, William Elgin, B.Sc., Ph.D. (Glas.), F.L.S., F.Z.S., F.G.S., Curator of Fossil Reptiles and Amphibia, British Museum (Natural History), South Kensington, London, S.W. 7	
1917	C. N.	* Tait, John, D.Sc., M.D., Professor of Physiology, McGill University, Montreal, Canada	

Date of Election			Service on Council, etc.
1933		* Tait, John Barclay, B.Sc. (Edin.), Ph.D., A.H.-W.C., Edinburgh, Junior Naturalist (Hydrographer), Marine Laboratory, Fishery Board for Scotland, Aberdeen. 23 Cromwell Road, Aberdeen	
1890	C.	† Tanakadate, Aikitu, Hon. Professor of Natural Philosophy, Imperial University of Japan. Koisikawa, Zôsigayamati, 144, Tokyo, Japan	
1870		Tatlock, Robert R., F.C.S., City Analyst's Office, 156 Bath Street, Glasgow	
1899		Taylor, James, M.A., formerly Mathematical Master, Edinburgh Academy. 18 Hillview, Blackhall, Edinburgh 4	
1933		* Taylor, George, D.Sc. (Edin.), F.L.S., Assistant Keeper, Department of Botany, British Museum. Ballochmyle, Loudwater, Rickmansworth, Herts	
1885	C.	Thompson, D'Arcy Wentworth, C.B., M.A., LL.D., D.Sc. (Witwatersrand), D.Litt., F.R.S. (PRESIDENT), Professor of Natural History, University, St Andrews. 44 South Street, St Andrews	1892–95, 1896–99, 1907–10, 1912–15, 1922–25. V-P 1916–19. Curator 1926–34. P 1934–
1932		Thompson, Harold William, D.Litt. (Edin.), A.M., Ph.D. (Harvard), F.S.A. Scot., Professor of English, N.Y. State College, Albany, N.Y., U.S.A.	
1917	C. N.	* Thompson, John M'Lean, M.A., D.Sc., F.L.S., Professor of Botany, University of Liverpool	
1896		Thomson, George Ritchie, C.M.G., M.B., C.M., formerly Professor of Surgery, University of the Witwatersrand, Johannesburg, Transvaal. Hordle Grange, Hordle, Hants	
1903		Thomson, George S., Kenmore Farm, Whelpley Hill, Chesham, Bucks	
1906		Thomson, Gilbert, M.A., M.Inst.C.E., 164 Bath Street, Glasgow, C. 2	
1926		* Thomson, Godfrey Hilton, D.Sc., Ph.D., Professor of Education, University of Edinburgh (Moray House)	1931–34.
1926	C.	* Thomson, John, M.A., Ph.D. (Glas.), Lecturer in Plant Physiology, University of Glasgow. 2 Chartwell Terrace, Bearsden, Glasgow	
1934		* Thomson, Matthew Sydney, M.A., M.D., B.Ch. (Cantab.), F.R.C.P., M.R.C.S., Physician for Diseases of the Skin, King's College Hospital, Belgrave Hospital for Children. 16 Harley Street, London, W. 1	
1899		Thomson, R. Tatlock, F.C.S., 156 Bath Street, Glasgow	
1912	C.	Thomson, Robert Black, M.B. (Edin.), Aliwal North, Cape Province, S.A.	
1882		Thomson, Sir William, Kt., M.A., B.Sc., LL.D., formerly Principal, University of the Witwatersrand. Dunedin, Glencairn, Simonstown, South Africa	
1917		* Thorneycroft, Wallace, J.P., Strete Ralegh, Whimple, Exeter, Devon	
1933		* Timms, Geoffrey, Ph.D. (Cantab.), Lecturer in Mathematics, University of St Andrews. Deanscourt, St Andrews	
1920		* Todd, John Barber, B.Sc., Ph.D., M.I.Mech.E., Reader in Engineering, University of Edinburgh. 4 Bright's Crescent, Edinburgh 9	
1917		* Tovey, Donald Francis, B.A. (Oxon.), M.Mus. (Hon.), Birmingham, Professor of Music, University of Edinburgh (Reid School of Music). 39 Royal Terrace, Edinburgh 7	
1914		† Tredgold, Alfred Frank, M.D. (Durham), F.R.C.P. (Lond.), Lecturer on Mental Deficiency, University of London. "St Martins," Guildford	
1915		* Trotter, George Clark, M.D. (Edin.), D.P.H. (Aberdeen), F.S.A.Scot., Medical Officer of Health, Metropolitan Borough, Islington. Braemar, 17 Haslemere Road, Crouch End, London, N. 8	
1922	C. K.	* Turnbull, Herbert Westren, M.A., F.R.S., Professor of Mathematics, University of St Andrews. 2 Queens Terrace, St Andrews	1928–31.
1905		Turner, Arthur Logan, M.D., LL.D., F.R.C.S.E., 27 Walker Street, Edinburgh 3	1926–29. V-P 1930–33.
1925		* Turner, Harry Moreton Stanley, M.B.E., M.D., M.R.C.S., L.R.C.P., D.T.M. and H., Chevalier de l'Ordre Royale du Sauveur de Grèce. Wing Commander, R.A.F. (retired). 65 Stert Street, Abingdon-on-Thames, near Oxford	
1924		* Turner, Richard, O.B.E., M.B., C.M., Hotel Hydropathic, Peebles	
1895		Turton, Albert H., M.Inst.M.M., 233 George Road, Erdington, Birmingham	

Date of Election			Service on Council, etc.
1918	C. N.	* Tyrrell, George Walter, A.R.C.S., D.Sc., F.G.S., Lecturer in Petrology, Geological Department, University of Glasgow	1926–29.
1930	C.	* Voge, Cecil Innes Bothwell, Ph.D. (Edin.), London School of Hygiene and Tropical Medicine, Keppel Street (Gower Street), London, W.C. 1	
1932		* Wade, Henry, C.M.G., D.S.O., M.D., Senior Lecturer in Clinical Surgery, University of Edinburgh (Royal Infirmary). 6 Manor Place, Edinburgh 3	
1926		* Wakeley, Cecil Pembrey Grey, F.R.C.S., Surgeon to King's College Hospital, London, Lecturer in Anatomy, King's College, London. 24 Queen Anne Street, Cavendish Square, London, W. 1	
1925	C.	* Walker, Frederick, M.A., Ph.D., D.Sc., Lecturer in Geology, University of St Andrews	
1891	C. M-B. V. J.	Walker, Sir James, Kt., D.Sc., Ph.D., LL.D., F.R.S., Emeritus Professor of Chemistry, University of Edinburgh. 5 Wester Coates Road, Edinburgh 12	1903–05, 1910–13, 1922–25, 1928–31. V-P 1916–19.
1931		* Walker, William James, Ph.D. (Edin.), Research Chemist, H.M. Fuel Research Station, East Greenwich, London, S.E. 10. C/o Harrison, 64 Sandtoft Road, Charlton, London, S.E. 7	
1902		Wallace, Alexander G., M.A., 56 Fonthill Road, Aberdeen	
1886	C.	Wallace, Robert, M.A., LL.D., F.L.S., Emeritus Professor of Agriculture and Rural Economy, University of Edinburgh. 10 Henderson Terrace, Edinburgh 11	
1898		Wallace, William, M.A., Campsie, Alta, Canada	
1920		* Walmsley, Thomas, M.D. (Glas.), Professor of Anatomy, Queen's University, Belfast	
1931	C.	* Walton, John, M.A. (Cantab.), D.Sc. (Manchester), Regius Professor of Botany, University of Glasgow. 23 Lilybank Gardens, Glasgow, W. 2	1934–
1927	C.	* Wardlaw, Claude Wilson, D.Sc. (Glas.), Imperial College of Tropical Agriculture, Trinidad, B.W.I.	
1923		* Warren, John Alexander, M.Inst.C.E. 74 Balshagray Avenue, Partick	
1901	C.	Waterston, David, M.A., M.D., F.R.C.S.E., Professor of Anatomy, University of St Andrews	1916–19, 1925–28.
1927		* Watson, Charles Brodie Boog, F.S.A.Scot. 24 Garscube Terrace, Edinburgh 12	
1923		* Watson, H. Ferguson, M.D., F.R.F.P.S., Ph.D., D.P.H. (Glas.), H.M. Senior Deputy Commissioner, General Board of Control for Scotland. 5 Hillside Street, Edinburgh 7	
1923	C.	* Watson, William, M.A., B.Sc. (Edin.), Lecturer in Physics, Heriot-Watt College, Edinburgh. 17 Braidburn Crescent, Edinburgh 10	
1911		† Watt, James, W.S., F.F.A., LL.D. (Treasurer), 7 Blackford Road, Edinburgh 10	1924–26. Treasurer 1926–
1933		* Watt, John Mitchell, M.B., Ch.B., M.R.C.P. (Edin.), F.R.S.S.A., Professor of Pharmacology, University of the Witwatersrand, Johannesburg, South Africa	
1911		* Watt, Right Rev. Lauchlan MacLean, D.D., LL.D., Kinloch, Lochcarron, Ross-shire	
1928		* Watters, Alexander Marshall, M.A., B.Sc. (Glas.), Rector of Hawick High School. High School House, Hawick	
1896		† Webster, John Clarence, B.A., M.D., F.R.C.P.E., formerly Professor of Obstetrics and Gynæcology, Rush Medical College, Shediac, N.B., Canada	
1907	M-B. C.	† Wedderburn, Ernest Maclagan, O.B.E., M.A., D.Sc., LL.B., W.S., Professor of Conveyancing, University of Edinburgh (South Bridge). 6 Succoth Gardens, Edinburgh 12	1913–16, 1921–24, 1932–
1903	M-B. C.	† Wedderburn, J. H. Maclagan, M.A., D.Sc., F.R.S., Professor of Mathematics, Princeton University. Fine Hall, Princeton, N.J., U.S.A.	
1904		Wedderspoon, William Gibson, M.A., LL.D.	
1934	C.	* Weir, John, M.A., Ph.D., D.Sc. (Glas.), Lecturer in Palæontology, University of Glasgow. 18 Botanic Crescent, Glasgow, N.W.	
1930		* White, Adam Cairns, M.B., Ch.B., Ph.D., Assistant Pharmacologist, Wellcome Physiological Research Laboratory, Beckenham, Kent	
1933		* Whitley, William Frederic James, M.D. (Edin.), D.P.H. (Oxon.), Medical Officer of Health, Northumberland County Council. Westfield, Cramlington, Northumberland	

Date of Election			Service on Council, etc.
1931		* Whitson, Sir Thomas Barnby, D.L., LL.D., C.A., Lord Provost of the City of Edinburgh (1929–32). 27 Eglinton Crescent, Edinburgh 12	
1911		* Whittaker, Charles Richard, F.R.C.S.E., F.S.A.Scot., Lynwood, Hatton Place, Edinburgh 9	
1912	C. V. J. B-P.	* Whittaker, Edmund Taylor, M.A., Hon. Sc.D. (Dubl.), Hon. LL.D. (St Andrews and California), F.R.S., Foreign Member of the R. Accademia dei Lincei, Rome, Professor of Mathematics, University of Edinburgh (16 Chambers Street). 48 George Square, Edinburgh 8	1912–15, 1922–25. Sec. 1916–22. V-P 1925–28.
1928	C.	* Whittaker, John Macnaghten, M.A. (Edin.), M.A. (Cantab.), D.Sc., Professor of Pure Mathematics, University of Liverpool	
1918		* Whyte, Rev. Charles, M.A., LL.D., F.R.A.S., U.F. Church Manse, Kingswells, Aberdeen	
1934		* Whyte, William, Cashier and General Manager of the Royal Bank of Scotland. Baberton House, Juniper Green, Edinburgh	
1929	C.	* Wiesner, Bertold Paul, D.Sc., formerly Macaulay Lecturer, Institute of Animal Genetics, University of Edinburgh. 3 Holly Terrace, Highgate Village, London, N. 6	
1918		* Wight, John Thomas, M.I.Mech.E., M.I.Mar.E., Joint Managing Director, Messrs MacTaggart, Scott & Co., Ltd., Loanhead. Calderwood Villa, Lasswade	
1934		* Wightman, William Persehouse Delisle, Ph.D., M.Sc. (Lond.), Science Master, Edinburgh Academy. 36 Coltbridge Terrace, Edinburgh 12	
1925		* Wilkie, David Percival Dalbreck, O.B.E., M.D., Ch.M., F.R.C.S., Professor of Surgery, University of Edinburgh (Royal Infirmary). 9 Ainslie Place, Edinburgh 3	
1926	C.	* Williams, Samuel, Ph.D., Lecturer in Plant Morphology, University of Glasgow. 27 Lindsay Place, Kelvindale, Glasgow	
1908		Williamson, Henry Charles, M.A., D.Sc., formerly Naturalist to the Fishery Board for Scotland. 11 St Mary's Road, Downfield, Dundee	
1928	C.	* Williamson, John, M.A. (Edin.), Ph.D. (Chicago), Associate Professor of Mathematics, Johns Hopkins University, Baltimore, U.S.A.	
1910	C.	Williamson, William, F.L.S., 7 Ventnor Terrace, Edinburgh 9	
1927	C.	* Williamson, William Turner Horace, B.Sc. (Aberd.), Ph.D. (Edin.), Chief Chemist, Egyptian Ministry of Agriculture, Cotton Research Board, Giza, Egypt	
1900		Wilson, Alfred C., Bloomfield House, Sadberge, near Darlington	
1911		* Wilson, Andrew, O.B.E., D.L., M.Inst.C.E., 66 Netherby Road, Edinburgh 5	
1934		* Wilson, Bertram Martin, M.A. (Cantab.), D.Sc. (Liverpool), Professor of Mathematics, University of St Andrews (University College, Dundee)	
1902	V. J.	† Wilson, Charles Thomson Rees, M.A., LL.D., D.Sc., F.R.S., Nobel Prize, Physics, 1927, Jacksonian Professor of Natural Philosophy, University of Cambridge. Glencorse, Storey's Way, Cambridge	
1922		* Wilson, John, F.R.I.B.A., Chief Architect, Scottish Department of Health. 20 Lomond Road, Edinburgh 5	
1920	C.	* Wilson, Malcolm, D.Sc. (London), A.R.C.S., F.L.S., Reader in Mycology and Bacteriology, University of Edinburgh (Royal Botanic Garden). Brent Knoll, Kinnear Road, Edinburgh 4	1931–34.
1924		* Wilson, William, M.A., LL.B., Advocate, Regius Professor of Public Law, University of Edinburgh (South Bridge). 38 Moray Place, Edinburgh 3	
1895		Wilson-Barker, Sir David, Kt., R.D., R.N.R., F.R.G.S., formerly Captain-Superintendent, Thames Nautical Training College, H.M.S. "Worcester." 12 Bolan Street, London, S.W. 11	
1934		* Winstanley, Arthur, M.B.E., D.Sc. (Eng.) (Lond.), M.I.Min.E., Mining Engineer to Safety in Mines Research Board. 18 St John's Road, Edinburgh 12	
1931	C.	* Wishart, John, M.A., B.Sc. (Edin.), M.A. (Cantab.), D.Sc. (Lond.), Reader in Statistics, University of Cambridge. Astræa, 18 Storey's Way, Cambridge	
1922	C. B.	* Wordie, James Mann, M.A. (Cantab.), B.Sc. (Glas.), 52 Montgomery Drive, Glasgow	
1933		* Wright, James, F.G.S., "Balado," 212 Colinton Road, Edinburgh 11	
1890		Wright, Johnstone Christie, Conservative Club, Edinburgh 2	

Date of Election			Service on Council, etc.
1896		† Wright, Sir Robert Patrick, LL.D., formerly Chairman of the Board of Agriculture for Scotland. The Heugh, North Berwick, East Lothian	
1911	C.	* Wrigley, Ruric Whitehead, M.A. (Cantab.), Assistant Astronomer, Royal Observatory, Edinburgh	
1882		Young, Frank W., C.B.E., F.C.S., H.M. Inspector of Schools (Emeritus). 35 Pentland Terrace, Edinburgh 10	
1904		Young, Robert B., M.A., D.Sc., F.G.S., Professor of Geology, University of the Witwatersrand (South African School of Mines and Technology), Johannesburg, Transvaal	

Number of Fellows, 727.

HONORARY FELLOWS OF THE SOCIETY.

(*At 22nd October* 1934.)

1920 HIS ROYAL HIGHNESS THE PRINCE OF WALES.
1934 HIS ROYAL HIGHNESS THE DUKE OF YORK.

FOREIGNERS (LIMITED TO FORTY-FOUR BY LAW I).

Elected

1933 John Jacob Abel, Professor of Pharmacology, Johns Hopkins University, Baltimore.
1916 Charles Eugène Barrois, formerly Professor of Geology and Mineralogy, Université, Lille, France. 41, Rue Pascal, Lille.
1923 Henri Bergson, Honorary Professor, College of France, Paris.
1930 Vilhelm Frimann Koren Bjerknes, Professor of Physics, Geophysical Institute, Bergen.
1927 Niels Bohr, Nobel Laureate, Physics, *1922*, Professor of Physics, University of Copenhagen.
1927 Jules Bordet, Nobel Laureate, Medicine, 1919, Professor of Bacteriology, University of Brussels.
1933 Filippo Bottazzi, Professor of Experimental Physiology, Royal Institute of Physiology, S. Andrea delle Dame, 21, Naples.
1923 Marcellin Boule, Professor at the National Museum of Natural History, Laboratory of Palæontology, 3 Place Valhubert, Paris 5^e.
1905 Waldemar Christofer Brögger, Professor of Mineralogy and Geology, K. Frederiks Universitet, Oslo.
1916 Douglas Houghton Campbell, Emeritus Professor of Botany, Stanford University, California.
1920 William Wallace Campbell, President-Emeritus of the University of California, Berkeley, Director-Emeritus of the Lick Observatory, Mt. Hamilton, California, and President of the National Academy of Sciences.
1930 Walter Bradford Cannon, Professor of Physiology, Harvard University, Cambridge, Mass.
1930 Maurice Caullery, Professor of Zoology in the University of Paris. Laboratoire d'Évolution des Êtres organisés, 105 Bould. Raspail, Paris, VI^e.
1933 Edwin Grant Conklin, formerly Professor of Biology, Princeton University, N.J.
1921 Reginald Aldworth Daly, Professor of Geology, Harvard University, Cambridge, Mass.
1927 Albert Einstein, Nobel Laureate, Physics, *1921*, Princeton University, N.J.
1913 George Ellery Hale, Honorary Director of Mount Wilson Observatory (Carnegie Institution of Washington), Pasadena, California.
1934 Björn Helland-Hansen, Geophysical Institute, Bergen.
1921 Johan Hjort, Professor of Marine Biology, University, Oslo.
1923 Arnold Frederik Holleman, Emeritus Professor of Organic Chemistry. University, Amsterdam. Boekensteijn Parkweg 7, Bloemendaal.
1934 Bernardo Houssay, Professor of Physiology, National University of Buenos Aires.
1933 Nikolaj Konstantinovic Koltzoff, formerly Professor of Zoology, State University, Moscow; Director of the Research Institute of Experimental Biology. Moscow 64, Voronzovo Pole 6.
1923 Tullio Levi-Civita, Professor of Mathematics, Regia Università, Rome.
1934 Frank Rattray Lillie, Professor of Zoology and Embryology, Whitman Laboratory, University of Chicago.
1927 Hans Horst Meyer, Emeritus Professor of Pharmacology, University of Vienna.
1934 Thomas Hunt Morgan, Nobel Laureate, Medicine, Professor of Biology, California Institute of Technology, Pasadena.
1923 Arthur Amos Noyes, Institute of Technology, Pasadena, California.
1908 Henry Fairfield Osborn, Research Professor of Zoology, Columbia University, Honorary President, American Museum of Natural History, New York, and Senior Geologist, U.S. Geological Survey.
1908 Ivan Petrovitch Pavlov, Emeritus Professor of Physiology, Academy of Sciences, Inst. Exper. Med., Nobel Laureate, Physiology and Medicine, 1904. V.O., 7 ligne No. 2, Leningrad.
1933 Albrecht Penck, Geheimrat Emeritus Professor of Geography, Friedrich-Wilhelms-Universität, Berlin.
1920 Charles Émile Picard, Perpetual Secretary, Academy of Sciences, Paris.

Elected

1921 Salvatore Pincherle, Professor of Mathematics, University of Bologna.

1920 Charles Richet, Nobel Laureate, Medicine, 1913, Professor of Physiology, Faculty of Medicine, Paris.

1934 Paul Sabatier, Nobel Laureate, Chemistry, Professor of Chemistry, University of Toulouse.

1934 Theobald Smith, formerly Director of the Rockefeller Institute for Medical Research, Princeton, New Jersey. 88 Battle Road, Princeton, N.J.

1930 Erik Helge Oswald Stensiö, Professor of Palæontology and Historical Geology, Royal University of Upsala.

1913 Vito Volterra, formerly Professor of Mathematical Physics, Regia Università. 17 Via in Lucina, Rome.

1910 Hugo de Vries, Emeritus Professor of Plant Anatomy and Physiology, Lunteren.

1927 Richard Willstätter, Nobel Laureate, Chemistry, 1915, Professor of Chemistry, University of Munich. Moehlstrasse 29, Munich 27.

1923 Edmund Beecher Wilson, formerly Professor of Zoology, Columbia University, New York.

1933 Pieter Zeeman, Nobel Laureate, Physics, 1902, Professor of Physics, University, Amsterdam.

Total, 41.

British Subjects (limited to twenty-two by Law I).

1934 Henry Edward Armstrong, Ph.D., LL.D., F.R.S., Emeritus Professor of Chemistry, Imperial College of Science and Technology, City and Guilds (Engineering) College, London. 55 Granville Park, London, S.E. 13.

1927 Sir William Henry Bragg, O.M., K.B.E., M.A., D.Sc., LL.D., F.R.S., Nobel Laureate, Physics, 1915, Fullerian Professor of Chemistry, Royal Institution, London.

1930 Sir Arthur Stanley Eddington, Kt., M.A., Hon. D.Sc., LL.D., F.R.S., Plumian Professor of Astronomy and Experimental Philosophy, University of Cambridge.

1927 Sir John Bretland Farmer, Kt., M.A., D.Sc., LL.D., F.R.S., Emeritus Professor of Botany, Imperial College of Science and Technology, London.

1900 Andrew Russell Forsyth, M.A., Sc.D., LL.D., Hon. Math.D., F.R.S., Emeritus Professor of Mathematics, Imperial College of Science and Technology, London; formerly Sadleirian Professor of Pure Mathematics, University of Cambridge.

1910 Sir James George Frazer, O.M., Kt., D.C.L., LL.D., Litt.D., F.R.S., Commandeur de la Légion d'Honneur. Trinity College, Cambridge.

1934 John Scott Haldane, C.H., M.A., M.D., LL.D., F.R.S., Director of the Mining Research Laboratory, and Honorary Professor, University of Birmingham. Cherwell, Oxford.

1927 Sir Frederick Gowland Hopkins, Kt., M.A., M.B., D.Sc., LL.D., President R.S., Joint Nobel Laureate, Medicine, 1929, Professor of Biochemistry, University of Cambridge.

1930 Sir Arthur Keith, Kt., M.D., LL.D., F.R.S., Master, Buckston Browne Research Farm, Downe, Farnborough, Kent.

1913 Sir Horace Lamb, Kt., M.A., Sc.D., D.Sc., LL.D., F.R.S., formerly Professor of Mathematics, University of Manchester. 6 Selwyn Gardens, Cambridge.

1910 Sir Joseph Larmor, Kt., M.A., D.Sc., LL.D., D.C.L., F.R.S., formerly Lucasian Professor of Mathematics, University of Cambridge. St John's College, Cambridge.

1933 Sir George Macdonald, K.C.B., LL.D., formerly Secretary, Scottish Education Department. 17 Learmonth Gardens, Edinburgh 4.

1934 Karl Pearson, M.A., LL.B., LL.D., F.R.S., Emeritus Galton Professor of Eugenics, University of London. 7 Well Road, London, N.W. 3.

1934 Edward Bagnall Poulton, M.A., D.Sc., LL.D., F.R.S., lately Hope Professor of Zoology, University of Oxford. Wykeham House, Banbury Road, Oxford.

1930 Robert Robinson, D.Sc., LL.D., F.R.S., Waynflete Professor of Chemistry, University of Oxford.

1921 Rt. Hon. Lord Rutherford of Nelson, O.M., M.A., D.Sc., B.A., LL.D., Past President R.S., Nobel Laureate, Chemistry, 1908, Cavendish Professor of Experimental Physics, University of Cambridge.

1933 Sir William Napier Shaw, Kt., Sc.D.(Cantab.), LL.D., F.R.S., formerly Director Meteorological Office. 10 Moreton Gardens, London, S.W. 5.

1908 Sir Charles Scott Sherrington, O.M., G.B.E., M.A., D.Sc., M.D., LL.D., Past President R.S., Joint Laureate, Nobel Prize, Medicine, 1932, Waynflete Professor of Physiology, University of Oxford.

1934 Sir Grafton Elliot Smith, Kt., M.A., M.D., Litt.D., F.R.S., Professor of Anatomy, University College, London. 62 Albert Road, London, N.W. 8.

1905 Sir Joseph John Thomson, O.M., Kt., D.Sc., LL.D., Past President R.S., Nobel Laureate, Physics, 1906, formerly Cavendish Professor of Experimental Physics, now Professor of Physics, University of Cambridge, Master of Trinity College, Cambridge.

1934 William Whitehead Watts, Sc.D., LL.D., F.R.S., Emeritus Professor of Geology, Imperial College of Science and Technology, London. Hillside, Langley Park, Sutton, Surrey.

Total, 21.

CHANGES IN FELLOWSHIP DURING SESSION 1933–1934.

FELLOWS OF THE SOCIETY ELECTED.

DAVID BAIN.
PATRICK BROUGH.
IVAN DE BURGH DALY.
FRANK FRASER DARLING.
DAVID RUTHERFORD DOW.
WILLIAM LEONARD EDGE.
IVOR MALCOLM HADDON ETHERINGTON.
GEORGE FRASER.
JOHN GLAISTER.
ROBERT MACLAGAN GORRIE.
DAVID HALDANE.
JOHN VERNON HARRISON.
SIR JOHN JEFFREY.
SIR WILLIAM CAMPBELL JOHNSTON.
R. CRANSTON LOW.
MAGNUS MOWAT.
WALTER GEORGE ROBERTSON MURRAY.
ALEXANDER ROBERT NORMAND.
RUDRENDRA KUMAR PAL.
HAROLD JAMES PLENDERLEITH.
DANIEL EDWIN RUTHERFORD.
HAROLD KEITH SALVESEN.
MATTHEW SYDNEY THOMSON.
JOHN WEIR.
WILLIAM WHYTE.
WILLIAM PERSEHOUSE DELISLE WIGHTMAN.
BERTRAM MARTIN WILSON.
ARTHUR WINSTANLEY.

HONORARY FELLOWS ELECTED.

HIS ROYAL HIGHNESS THE DUKE OF YORK.

FOREIGN.

BJÖRN HELLAND-HANSEN.
BERNARDO HOUSSAY.
FRANK RATTRAY LILLIE.
THOMAS HUNT MORGAN.
PAUL SABATIER.
THEOBALD SMITH.

BRITISH.

HENRY EDWARD ARMSTRONG.
JOHN SCOTT HALDANE.
KARL PEARSON.
EDWARD BAGNALL POULTON.
SIR GRAFTON ELLIOT SMITH.
WILLIAM WHITEHEAD WATTS.

FELLOWS DECEASED.

ARTHUR HENRY HALLAM ANGLIN.
FREDERICK ALEXANDER BLACK.
HENRY MOUBRAY CADELL.
GEORGE COULL.
JAMES BELL DOBBIE.
JAMES COSSAR EWART.
JAMES HAIG FERGUSON.
SIR ALEXANDER CRUIKSHANK HOUSTON.
ANDREW WILLIAM KERR.
DAVID LEES.
ALEXANDER VEITCH LOTHIAN.
SIR DONALD MACALISTER, BART.
DAVID CLARK THOMSON MEKIE.
SIR THOMAS MUIR.
ARTHUR J. PRESSLAND.
CHARLES EDWARD PRICE.
THE HON. LORD SANDS.
JAMES YOUNG SIMPSON.
ROBERT SOMERVILLE.
DUNCAN M'LAREN YOUNG SOMMERVILLE.
SWALE VINCENT.

FOREIGN HONORARY FELLOW DECEASED.

SANTIAGO RAMÓN Y CAJAL.

BRITISH HONORARY FELLOWS DECEASED.

SIR WILLIAM BATE HARDY.
SIR ARTHUR SCHUSTER.
DUKINFIELD HENRY SCOTT.

FELLOW RESIGNED.

DAVID ARMITAGE BANNERMAN.

LAWS OF THE SOCIETY.

Adopted July 3, 1916; *amended December* 18, 1916.

LAW I,	amended February 5, 1934.		LAW IX,	amended May 3, 1920.
,, VI,	,, ,, 7, 1921.		,, XIII,	,, May 3, 1920.
,, ,,	,, July 2, 1928.		,, XIX,	,, June 16, 1924.
,, VIII,	,, May 3, 1920.			

I.

THE ROYAL SOCIETY OF EDINBURGH, which was instituted by Royal Charter in 1783 for the promotion of Science and Literature, shall consist of Ordinary Fellows (hereinafter to be termed Fellows) and Honorary Fellows. The number of Honorary Fellows shall not exceed sixty-six, of whom not more than twenty-two may be British subjects, and not more than forty-four subjects of Foreign States.

Fellows only shall be eligible to hold office or to vote at any Meeting of the Society.

ELECTION OF FELLOWS.

II.

Each Candidate for admission as a Fellow shall be proposed by at least four Fellows, two of whom must certify from personal knowledge. The Official Certificate shall specify the name, rank, profession, place of residence, and the qualifications of the Candidate. The Certificate shall be delivered to the General Secretary before the 30th of November, and, subject to the approval of the Council, shall be exhibited in the Society's House during the month of January following. All Certificates so exhibited shall be considered by the Council at its first meeting in February, and a list of the Candidates approved by the Council for election shall be issued to the Fellows not later than the 21st of February.

III.

The election of Fellows shall be by Ballot, and shall take place at the first Ordinary Meeting in March. Only Candidates approved by the Council shall be eligible for election. A Candidate shall be held not elected, unless he is supported by a majority of two-thirds of the Fellows present and voting.

IV.

On the day of election of Fellows two scrutineers, nominated by the President, shall examine the votes and hand their report to the President, who shall declare the result.

V.

Each Fellow, after his election, is expected to attend an Ordinary Meeting, and sign the Roll of Fellows, he having first made the payments required by Law VI. He shall be introduced to the President, who shall address him in these words:—

In the name and by the authority of THE ROYAL SOCIETY OF EDINBURGH, I admit you a Fellow thereof.

PAYMENTS BY FELLOWS.

VI.

Each Fellow shall, before he is admitted to the privileges of Fellowship, pay an admission fee of three guineas, and a subscription of three guineas for the year of election. He shall continue to pay a subscription of three guineas at the beginning of each session so long as he remains a Fellow.

Each Fellow who was elected subsequent to December 1916 and previous to December 1920 shall also pay a subscription of three guineas at the beginning of each session so long as he remains a Fellow.

Each Fellow who was elected previous to December 1916, and who has not completed his twenty-five annual payments, shall, at the beginning of each session, pay three guineas until his twenty-five annual payments are made. Each Fellow who has completed or shall complete his payments shall be invited to contribute one guinea per annum or to pay a single sum of ten guineas.

A Fellow may compound for the annual subscriptions by a single payment of fifty guineas, or on such other terms as the Council may from time to time fix.

VII.

A Fellow who, after application made by the Treasurer, fails to pay any contribution due by him, shall be reported to the Council, and, if the Council see fit, shall be declared no longer a Fellow. Notwithstanding such declaration all arrears of contributions shall remain exigible.

ELECTION OF HONORARY FELLOWS.

VIII.

Honorary Fellows shall be persons eminently distinguished in Science or Literature. They shall not be liable to contribute to the Society's Funds. Personages of the Blood Royal may be elected Honorary Fellows at any time on the nomination of the Council, and without regard to the limitation of numbers specified in Law I.

IX.

Honorary Fellows shall be proposed by the Council. The nominations shall be announced from the Chair at the First Ordinary Meeting after their selection. The names shall be printed in the circular for the last Ordinary Meeting of the Session, when the election shall be by Ballot, after the manner prescribed in Laws III and IV for the Election of Fellows.

EXPULSION OF FELLOWS.

X.

If, in the opinion of the Council, the conduct of any Fellow is injurious to the character or interests of the Society, the Council may, by registered letter, request him to resign. If he fail to do so within one month of such request, the Council shall call a Special Meeting of the Society to consider the matter. If a majority consisting of not less than two-thirds of the Fellows present and voting decide for expulsion, he shall be expelled by declaration from the Chair, his name shall be erased from the Roll, and he shall forfeit all right or claim in or to the property of the Society.

XI.

It shall be competent for the Council to remove any person from the Roll of Honorary Fellows if, in their opinion, his remaining on the Roll would be injurious to the character or interests of the Society. Reasonable notice of such proposal shall be given to each member of the Council, and, if possible, to the Honorary Fellow himself. Thereafter the decision on the question shall not be taken until the matter has been discussed at two Meetings of Council, separated by an interval of not less than fourteen days. A majority of two-thirds of the members present and voting shall be required for such removal.

MEETINGS OF THE SOCIETY.

XII.

A Statutory Meeting for the election of Council and Office-Bearers, for the presentation of the Annual Reports, and for such other business as may be arranged by the Council, shall be held on the fourth Monday of October. Each Session of the Society shall begin at the date of the Statutory Meeting.

XIII.

Meetings for reading and discussing communications and for general business, herein termed Ordinary Meetings, shall be held, when convenient, on the first and third Mondays of each month from November to July inclusive, with the exception that in January the meetings shall be held on the second and fourth Mondays.

XIV.

A Special Meeting of the Society may be called at any time by direction of the Council, or on a requisition to the Council signed by not fewer than six Fellows. The date and hour of such Meeting shall be determined by the Council, who shall give not less than seven days' notice of such Meeting. The notice shall state the purpose for which the Special Meeting is summoned; no other business shall be transacted.

PUBLICATION OF PAPERS.

XV.

The Society shall publish Transactions and Proceedings. The consideration of the acceptance, reading, and publication of papers is vested in the Council, whose decision shall be final. Acceptance for reading shall not necessarily imply acceptance for publication.

DISTRIBUTION OF PUBLICATIONS.

XVI.

Fellows who are not in arrear with their Annual Subscriptions and all Honorary Fellows shall be entitled gratis to copies of the Parts of the Transactions and the Proceedings published subsequently to their admission.

Copies of the Parts of the Proceedings shall be distributed by post or otherwise, as soon as may be convenient after publication; copies of the Transactions or Parts thereof shall be obtainable upon application, either personally or by an authorised agent, to the Librarian, provided the application is made within five years after the date of publication.

CONSTITUTION OF COUNCIL.

XVII.

The Council shall consist of a President, six Vice-Presidents, a Treasurer, a General Secretary, two Secretaries to the Ordinary Meetings (the one representing the Biological group and the other the Physical group of Sciences),* a Curator of the Library and Museum, and twelve ordinary members of Council.

ELECTION OF COUNCIL.

XVIII.

The election of the Council and Office-Bearers for the ensuing Session shall be held at the Statutory Meeting on the fourth Monday of October. The list of the names recommended by the Council shall be issued to the Fellows not less than one week before the Meeting. The election shall be by Ballot, and shall be determined by a majority of the Fellows present and voting. Scrutineers shall be nominated as in Law IV.

XIX.

The President may hold office for a period not exceeding five consecutive years; the Vice-Presidents, not exceeding three; the Secretaries to the Ordinary Meetings, not exceeding five; the General Secretary, the Treasurer, and the Curator of the Library and Museum, not exceeding ten; and ordinary members of Council, not exceeding three consecutive years; provided that the Treasurer may be re-elected for more than ten successive years in cases where the Council declares to the Society that an emergency exists.

XX.

In the event of a vacancy arising in the Council or in any of the Offices enumerated in Law XVII, the Council shall proceed, as soon as con-

* The Biological group includes Anatomy, Anthropology, Botany, Geology, Pathology, Physiology, Zoology; the Physical group includes Astronomy, Chemistry, Mathematics, Metallurgy, Meteorology, Physics.

venient, to elect a Fellow to fill such vacancy for the period up to the next Statutory Meeting.

POWERS OF THE COUNCIL.

XXI.

The Council shall have the following powers:—(1) To manage all business concerning the affairs of the Society. (2) To decide what papers shall be accepted for communication to the Society, and what papers shall be printed in whole or in part in the Transactions and Proceedings. (3) To appoint Committees. (4) To appoint employees and determine their remuneration. (5) To award the various prizes vested in the Society, in accordance with the terms of the respective deeds of gift, provided that no member of the existing Council shall be eligible for any such award. (6) To make from time to time Standing Orders for the regulation of the affairs of the Society. (7) To control the investment or expenditure of the Funds of the Society.

At Meetings of the Council the President or Chairman shall have a casting as well as a deliberative vote.

DUTIES OF PRESIDENT AND VICE-PRESIDENTS.

XXII.

The President shall take the Chair at Meetings of Council and of the Fellows. It shall be his duty to see that the business is conducted in accordance with the Charter and Laws of the Society. When unable to be present at any Meetings or attend to current business, he shall give notice to the General Secretary, in order that his place may be supplied. In the absence of the President his duties shall be discharged by one of the Vice-Presidents.

DUTIES OF THE TREASURER.

XXIII.

The Treasurer shall receive the monies due to the Society and shall make payments authorised by the Council. He shall lay before the Council a list of arrears in accordance with Rule VII. He shall keep accounts of all receipts and payments, and at the Statutory Meeting shall present the accounts for the preceding Session, balanced to the 30th of September, and audited by a professional accountant appointed annually by the Society.

DUTIES OF THE GENERAL SECRETARY.

XXIV.

The General Secretary shall be responsible to the Council for the conduct of the Society's correspondence, publications, and all other business except that which relates to finance. He shall keep Minutes of the Statutory and Special Meetings of the Society and Minutes of the Meetings of Council. He shall superintend, with the aid of the Assistant Secretary, the publication of the Transactions and Proceedings. He shall supervise the employees in the discharge of their duties.

DUTIES OF SECRETARIES TO ORDINARY MEETINGS.

XXV.

The Secretaries to Ordinary Meetings shall keep Minutes of the Ordinary Meetings. They shall assist the General Secretary, when necessary, in superintending the publication of the Transactions and Proceedings. In his absence, one of them shall perform his duties.

DUTIES OF CURATOR OF LIBRARY AND MUSEUM.

XXVI.

The Curator of the Library and Museum shall have charge of the Books, Manuscripts, Maps, and other articles belonging to the Society. He shall keep the Card Catalogue up to date. He shall purchase Books sanctioned by the Council.

ASSISTANT SECRETARY AND LIBRARIAN.

XXVII.

The Council shall appoint an Assistant Secretary and Librarian, who shall hold office during the pleasure of the Council. He shall give all his time, during prescribed hours, to the work of the Society, and shall be paid according to the determination of the Council. When necessary he shall act under the Treasurer in receiving subscriptions, giving out receipts, and paying employees.

ALTERATION OF LAWS.

XXVIII.

Any proposed alteration in the Laws shall be considered by the Council, due notice having been given to each member of Council. Such alteration, if approved by the Council, shall be proposed from the Chair at the next Ordinary Meeting of the Society, and, in accordance with the Charter, shall be considered and voted upon at a Meeting held at least one month after that at which the motion for alteration shall have been proposed.

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